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VALUE ENGINEERING OF INNOTRACK™

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ABSTRACT

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Value engineering of InnoTrack™

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Middle section module of InnoTrack™ moving walk was re-engineered according to value analysis process. Self-supporting steel structure for moving walk was created as a result of this process. Designed structure was verified and validated by prototype tests and finite element method calculations. Self-supporting steel structure replaces the original design of middle section module in InnoTrack™. Designed structure provides higher satisfaction to customers' needs and at the same time, it uses less resources. The redesigned middle section module provides higher value to the customer.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto

Teknillinen tiedekunta

LUT Kone

Tomi Sipilä

InnoTrack^{TM} liukukäytävän arvoanalyysiin perustuva suunnittelu

Diplomityö

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InnoTrack^{TM} liukukäytävän keskimoduuli suunniteltiin uudelleen käyttäen arvoanalyysiä. Prosessin lopputuloksena syntyi itsensä kantava teräsrakenne, joka täyttää liukukäytävän keskimoduulilta vaadittavat tehtävät. Suunniteltu rakenne on todettu käyttökelpoiseksi prototyyppitestauksella sekä elementtimenetelmään perustuvilla laskelmilla. Itsensä kantava rakenne korvaa edellisen keskimoduulin InnoTrack^{TM} liukukäytävässä. Suunniteltu uusi keskimoduuli vastaa paremmin asiakkaan tarpeita kuin alkuperäinen rakenne. Samaan aikaan rakenteen kustannukset ovat pienemmät kuin alkuperäisen keskimoduulin. Suunniteltu keskimoduuli tarjoaa korkeamman arvon asiakkaalle.

PREFACE

My master thesis is finally ready and my graduation is closer than ever. It is time to thank everyone who has supported me with my work. It was a great experience to work abroad and write my thesis for KONE Elevators in Kunshan, China.

First I want to thank my instructor Ralf Weber and my manager Qian Jinming, Jimmy for giving me this opportunity and supporting me with my work. I thank also my examiners Aki Mikkola and Kimmo Kerkkänen.

I would like to thank all KONE employees in China and in Europe who have supported me with my work. Special thanks to Antti Mäki, Jani Tertsonen, Benjamin Guerin, Yao Hong Bin, Gary, Andreas Minch and Arttu Hult. I thank also my friends in Finland and my new friends who I got to know while living in China.

The most grateful I'm from the support and help that I have got from my girlfriend, mother, father and sister.

Helsinki, February 2014

Tomi Sipilä

TABLE OF CONTENTS

1 INTRODUCTION

"The KONE InnoTrack^{TM} is the first autowalk that doesn't need a pit. Its revolutionary design allows it to be brought to the site 'through the door' instead of 'through the wall'. You can install it in finished buildings on any floor. You can shorten it, lengthen it, change the color or re-install it somewhere else" (KONE Corporation b, 2006).

Figure 1. KONE InnoTrack^{TM} (KONE Corporation a, 2006)

KONE InnoTrack^{TM} is one of the most innovative products that KONE Corporation has. It is a moving walk that customer can install on a finished floor. Due to the configurable structure it is possible to re-install the unit in different location if needed. InnoTrack^{TM} consists of four main modules drive head, tension head, middle section and access ramps. Each of the modules contains variety of different innovations that enable the flat design. InnoTrack^{TM} uses gearless drive, known from KONE elevators, to power the pallet operation system. Figure 2 presents how the electric drive is installed inside of the newel. Pallet operation system uses KONE ThinReverser^{TM} which directs pallets to return directly under the walking level instead of circling them around. Middle section is based on two KONE CombiRail^{TM} tracks. These tracks are extruded from aluminum. Profile has interfaces which allow integrating different components to the profile. (KONE Corporation b, 2006)

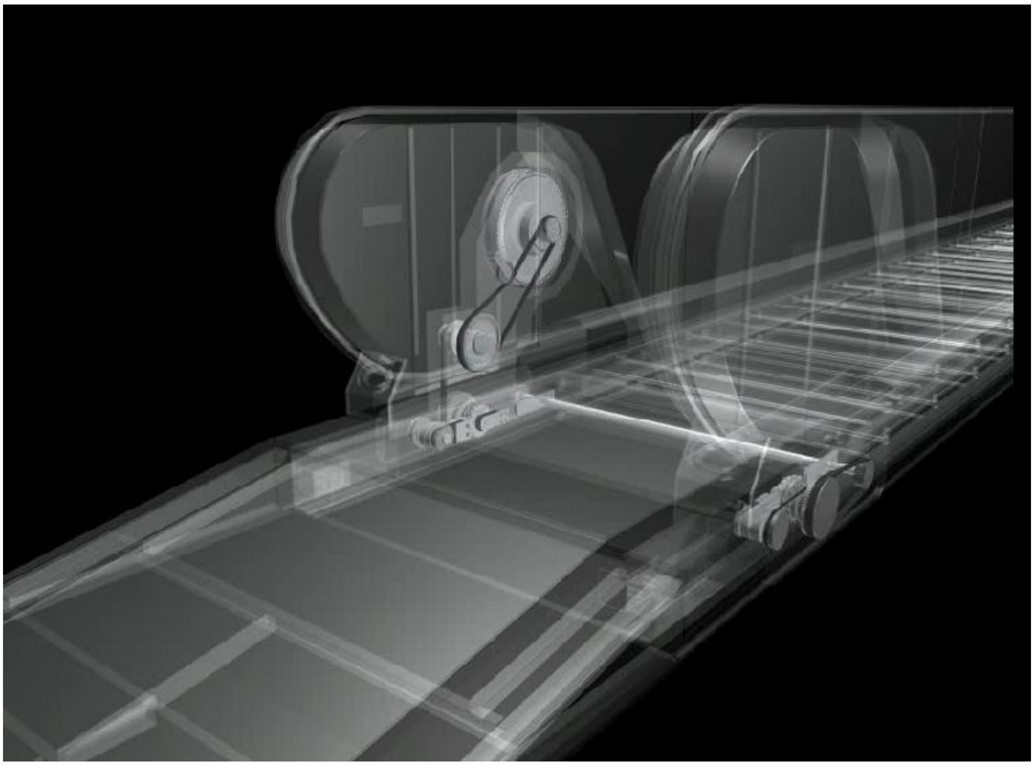


Figure 2. Transparent picture of the InnoTrack^{TM} (KONE Corporation a, 2006)

Markets for autowalks are not as big as markets for escalators or elevators. Volumes for KONE autowalks are calculated usually in hundreds per year instead of thousands like for escalators. In year 2006 KONE released InnoTrack^{TM} and created a new market area for moving walks, flat autowalk. However InnoTrack^{TM} has not been able to achieve the business targets that were set. The reason for this is simple; unit purchasing price is too high for most of the customers. Customers are not getting satisfaction to their money. However the markets for flat autowalks exists as InnoTrack^{TM} is still arousing interest among customers. There is another similar unit on the markets and according to the information in KONE technology organization this rival unit has higher volume than InnoTrack^{TM}. Purchasing price for this unit is expected to be significantly lower. (KONE Corporation b, 2006)

Value is considered as a relationship between satisfaction of the needs and the recourses used in doing so. Designing products that give the most value to the customer is important. Value-added products, recognized by customer are more likely to be successful. To be successful InnoTrack^{TM} needs to provide enough value to the customer. Current price of InnoTrack^{TM} is more than five times higher compared to a conventional KONE moving walk. Therefore it is believed that the unit is not providing enough satisfaction to customer's needs. It is simply due to the reason that customers are not willing to pay five times more for the extra functions that InnoTrack^{TM} has to offer compared to conventional moving walk. (Cavalca & Teixeira, 2007; EN 12973, 2000)

The idea for current InnoTrack^{TM} design started from the CombiRail^{TM} track profile. This extruded aluminum profile enables easy fixing interfaces for different components which allow simple installation on site. KONE CombiRail^{TM} tracks require heavy extruding machine. Only limited number of suppliers can deliver this kind of profile. The size together with high tolerance demands is increasing the price of the component. When investigating the cost model of InnoTrack^{TM} device it can be seen that the middle section module is not the most expensive module. However the middle section module and the aluminum profile are considered to be the bottle neck for more valuable design as it limits the options to develop other modules. Due to these mentioned reasons it is important to re-engineer the middle section module. (KONE Corporation b, 2006)

There are two main problems for this re-engineering. The first problem is how to modify the middle section so that it gives more value to customer. The second problem is how to ensure the configurability of the modified unit.

1.1 Target and designing scope

As mentioned the extruded aluminum profile is considered to be the bottle neck of more valuable design for InnoTrack^{TM}. By re-engineering the middle section it is possible to increase the value that customer gets when purchasing InnoTrack^{TM} unit. This thesis will manage re-engineering of InnoTrack^{TM} middle section module according to the principles of value engineering.

Target for this master thesis is to increase the amount of value that the InnoTrack^{TM} middle section provides to customer. Re-engineering is to be done without changing the critical dimensions of the module or by changing the characteristics that enable flat and configurable design. Changes to the pallet reverser system are not in the scope of this thesis. Main focus is on the load carrying structure and to provide safe and reliable ride along the middle section of an autowalk.

Design must meet applicable requirements in European standard EN 115-1 Safety of escalators and moving walks Part 1: Construction and installation. Passenger safety has to be ensured in every case. Designed structure and components must achieve acceptable level of reliability.

2 VALUE ENGINEERING

Value engineering started in 1940's during the World War II. Lawrence D Miles developed a technique of value analysis to add value to the existing products. Value analysis was initially used to seek and eliminate unnecessary costs. However soon it was discovered that it is as powerful tool to increase products performance or addressing costs. Value analysis is not limited only to products it can be used also for services or project management. (Cavalca & Teixeira, 2007)

In product development value analysis is a well-known method. It relies on the concept of value, relationship between satisfaction of the need and cost. As mentioned value analysis is often used to increase the product value or decrease product costs. By applying value analysis process in product development it is possible to determine a value hierarchy between different solutions. Decision between possible solutions can be then rationalized. (Romano, Formantini, Bandera, & Tomasella, 2010)

Over the years several different value methods have been developed. Value management standard EN 12973 introduces five different methods, value analysis, function cost, functional performance specification and design to cost / design to objectives. Value analysis is the basis for most of these methods and it is a powerful and one of the most frequently used methods to undertake value studies. Value management standard EN 12973 provides a guideline how to manage the value analysis. This guideline is based on a book, Techniques for value analysis and engineering by Lawrence D Miles. (EN 12973, 2000)

This master thesis will follow guideline of value analysis to manage the modifications of the InnoTrack^{TM}. Value analysis will take influences from the standard and from the book Techniques for value analysis and engineering. According to EN 12973 value methods can be used concurrently with other specific methods. In this thesis work modular design and design for manufacture and assembly (DFMA) will be also used to support the value analysis. (EN 12973, 2000, p. 29)

2.1 Concept of Value

Standard EN 1325-1 determines that value is "*The relationship between the contribution of the* ***function*** *(or* ***VA subject)*** *to the satisfaction of the need and the cost of the function (or VA* ***subject).*** **"**(EN 1325-1, 1996, p. 7)

$$Value = \frac{Satisfaction\ of\ needs}{Resources} \tag{1}$$

Relationship between satisfaction of needs and resources is shown in equation 1. A product is considered to have great value if it has appropriate performance and cost. On the other hand value is low if the product lacks of either appropriate cost or performance. Value is always related to the customer's needs. Different parties have different view point and therefore value can never be absolute. (Miles, 1989, p. 5)

By balancing the satisfied needs against the used resources it is possible to optimize the value. In able to do so value must be determined and quantified. It is important to realize that value can be increased in many ways. Value of the product will increase if the product gives much more satisfaction even if it uses more resources. In this case the satisfaction of needs grows more than the used resources. According to this principle value will increase also if the product uses much less resources and same time gives little less satisfaction. (EN 12973, 2000, p. 17)

2.1.1 Satisfaction of needs

Need is something that customer desires or necessary wants. Objectively needs can be considered as the functions of a product. Functions will provide satisfaction to the customer. According to Lawrence D Miles there are only two types of functions: use and aesthetic functions. Use functions can be measured and they are concrete. Aesthetic or esteem functions are subjective, attractive or moral and can't be measured. If it is not possible to measure the need in monetary term it should be evaluated by a study team. The key is to define the needed functions and provide a product that satisfies the needs. (EN 12973, 2000, pp. 17-18; Miles, 1989, p. 26)

2.1.2 Resources

“All cost is for function” says Lawrence D Miles. This is the message also in EN 12973. Resources cover everything that is required to satisfy the needs. Long and short term costs, time, materials and other inputs are all resources. Input can be either physical such as materials or abstract like intellectual property. Generally all resources can be related to costs. Some resources are more important than others, for example time, and the availability can be the driven factor instead of the monetary cost. (EN 12973, 2000, p. 15; Miles, 1989, p. 25)

For an existing product current use of resources can be measured. These resources should form the basis from which improvements can be measured. After quantifying the use of resources and satisfaction of needs, the ratio between them will provide a measure of value which can be used for comparison. (EN 12973, 2000, p. 15)

2.2 Value Analysis Job Plan

Value management standard EN 12973 introduces nine different steps and Lawrence D Miles five steps to manage value analysis. Both techniques have the same goal and the processes are similar with each other. Where five steps introduced in Techniques of value analysis and engineering concentrates more to set the functions needed in a product and solving the stated matters, EN 12973 concentrates to the whole project and how to manage it. Standard contains the same steps introduced by Lawrence D Miles and the final steps are how to complete the project. (EN 12973, 2000, pp. 33-41; Miles, 1989, pp. 54-59)

Job plan for this thesis work is a six step process and it will combine both approaches in certain steps. Job plan recognizes the problems and defines the needs of satisfaction. Figure 3 introduces 6 steps for the value analysis. (EN 12973, 2000, p. 31)

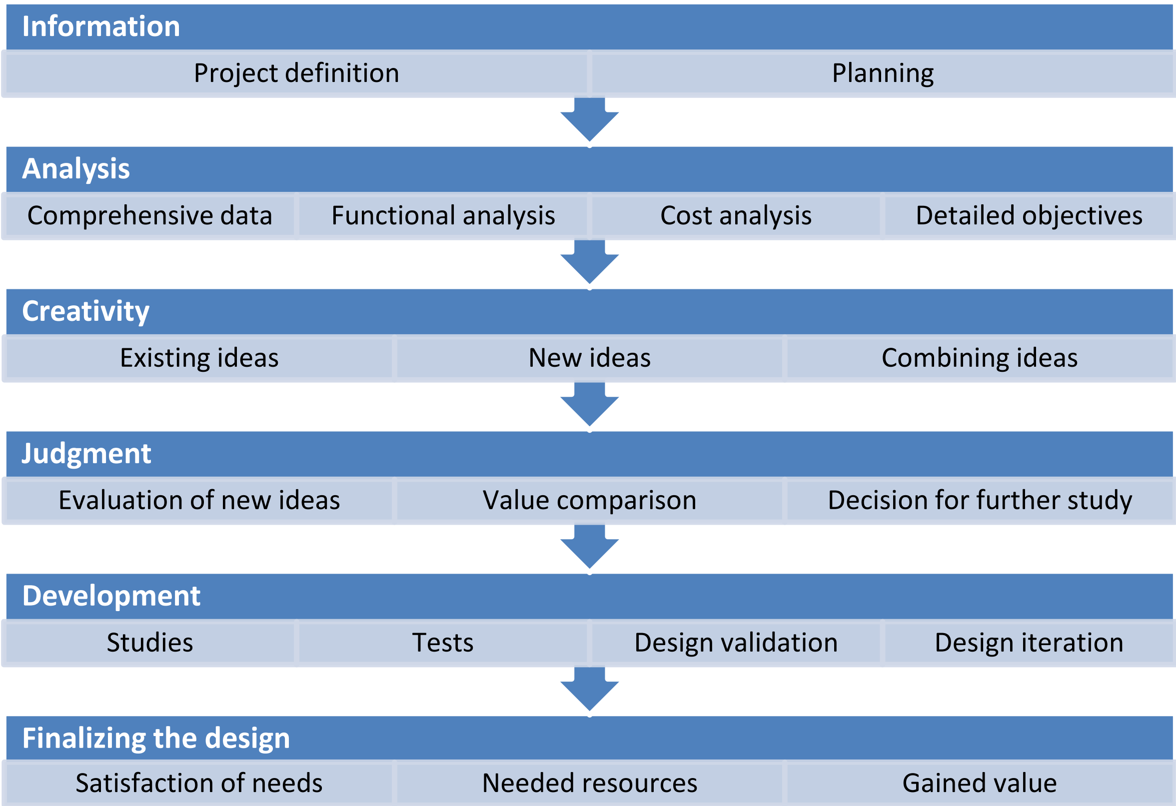


Figure 3. Value analysis - job plan (Fang & Rogerson, 1999; EN 12973, 2000; Miles, 1989)

2.2.1 Information step

Good understanding of the subject will create effective foundation to the work. Without the knowledge of the facts and truths it is impossible to be effective. Thoroughly done information step will often help to find solutions rapidly. Project definition and planning will be done in information step. It is usually easier to develop some design if one knows the originals reasons why something was done and why the solutions are what they are. Focus in information step is to find out facts, assumptions and information needed but not known. (EN 12973, 2000; Miles, 1989, p. 54)

To have understanding of the original solution one should study the original design. Part of this study is to explore the relevant documents for the solution from business case to project plan and closing report. Communication with original designers and employees who have been involved with the original solution is essential. Communication with these employees and project documentations will provide a base for understanding of the current design. In case of InnoTrack™ the original designers have left the company but there are still employees at KONE who have been working with InnoTrack^{TM} unit. Project documentation for InnoTrack^{TM} has been archived in KONE product data management system. (EN 12973, 2000; Miles, 1989, p. 54)

Understanding of the customer needs is crucial for value analysis. Reasons behind the needs can be from customer survey or they can be based on the knowledge of the markets. Innovations can provide new types of satisfaction to the customer. Comprehensive customer satisfaction inquiry provides good understanding of the current state of the satisfaction. Innovative solution can also create new yet unknown ways to satisfy the customer needs. These needs might not be visible in a survey. There is no possibility to make comprehensive customer satisfaction inquiry in the limits of this master thesis work. Customer needs are based on knowledge in KONE technology organization. Author will gather necessary information from KONE archives and by communicating employees inside KONE technology organization. (Miles, 1989, p. 54)

Goal of the information step is to gather information regarding the original design of the InnoTrack^{TM}. Gather background why the original project was started and why the designers ended up with the current solution. What ideas did they have but didn't use? After information step it is also clear what the customer needs are. (EN 1325-1, 1996; Miles, 1989, p. 54)

2.2.2 Analysis step

Analysis step gathers comprehensive data about the study and sets problems for the project. Step one in setting the problems is to identify functions that are needed. Function is concerned to be a task or an action that system is capable to do. What are the functions in InnoTrack^{TM} middle section that the customer is willing to pay for? In this step it is important to understand the customer's needs. These needed functions are the main functions. They must be named and studied in the limits under which each function must operate. Step two will divide main functions to sub functions. Sub functions are functions that must be accomplished in order to achieve the main functions.(EN 12973, 2000; Miles, 1989, p. 55)

A set of questions can be asked to find needed functions. Table 1 introduces questions which are asked in a value analysis process. With an active verb and measurable noun it is normal to express functions. Needed functions are studied with help of value tree. Value tree is modification from Function Analysis Systems Technique (FAST) diagram. The goal of value tree diagram is to set the functions visible and also link them to respond *how?* and *why?* questions. In the value tree the customer need is presented on the left. "How-why" relations is used to identify the needed functions to provide the customer need. One moves from left to right by asking *how?* and right to left by asking *why?* (Hamilton, 2002; EN 12973, 2000; Fang & Rogerson, 1999)

Table 1: Common questions asked in a value analysis process (Ho, Cheng, & Fong, 2000)

Question	Objective
What does it do?	Identify the basic function
What else does it do?	Identify the secondary function
What does it cost?	Identify the cost
Is the function really required?	Search for unnecessary functions
Are there other alternatives which can deliver the same function	Generate cheaper ways of performing the same function

Functional groups can be created once the needed functions are clear. Each function group has a specified, well-defined and well-understood task. According to the created function groups the original design is analyzed. The goal for this is to break the overall problem into number of specific problems. Thoroughly done analysis provides basis for creativity step and specified problems will simplify this process. (Miles, 1989, pp. 44-47,54)

2.2.3 Creativity step

According to Lawrence D Miles one needs to associate right combinations of creativity and knowledge to find new solutions. Creativity is a brainstorming activity and every possible solution should be considered as equal possibility. Judging of new solutions should be avoided in creativity step. Creativity step is to find different, existing and new ideas. Understanding of the product and information of the needed functions is the basis for creating possible solutions for problems. Different methods should be used to accelerate the creativity activities. Previously presented value tree is one example of these acceleration methods. (EN 12973, 2000; Miles, 1989, p. 56)

Brainstorming activity was introduced by Alex Osborn in the 1953 book Applied Imagination. Term is popularized since and method widely used. Essential for brainstorming is that there is no judging. Goal is to gather maximum number of ideas. Combine different ideas and eventually improve the existing solution. New designs are generated by creating new solutions to carry out the same task as the original function group. The needed functions are visible in the value tree and broken down to specific problems, function groups. Goal for creativity step is to create different solutions for InnoTrack^{TM} middle section. These solutions should differ from each other in a way that clear comparison can be done for the solutions. (Business Management Daily, 2013; EN 12973, 2000; Miles, 1989, p. 56)

2.2.4 Judgment step

Judgment step is to study created ideas. It will determine the limitations of each idea and seek to eliminate, overcome, or minimize the objections. Created ideas will be compared to each other and judged by how well they accomplish the needed functions. Value of each idea is compared with the help of costs. Decision on which ideas will be further developed and improved will be based on the value that the idea gives to the customer. (EN 12973, 2000, p. 40; Miles, 1989, p. 58)

Since the goal is to increase the value which is a relation between functions and costs it is necessary to evaluate this relation with comparison. For the comparison calculated values needs to be comparable. When calculating value the used resources should cover all used resources. In case like this master thesis where the product is new and there is no data about life time costs one should evaluate the main factors and compare those. (EN 12973, 2000; Ho, Cheng, & Fong, 2000)

2.2.5 Development and validation step

In creativity step all ideas are treated equally where as in validation step the ideas are focused on to provide solution that meets needed requirements. Development step gathers the most suitable ideas and combines them for the most suitable solution. Study cases presented in Techniques for value analysis and engineering book shows that whenever there is an alternative way to accomplish specific task new questions will arise. These questions should be used to develop the structure to provide the utmost value. (Ibusuki & Kaminski, 2007; Miles, 1989, p. 61)

Potentiality to add value is created in creativity step. The most potential solution is chosen based on judgment step. To redeem this potential the solution is to be validated. In field of mechanical design the created solutions can be validated for example by proving a compliance with relevant standard. In case of a moving walk there is a safety standard which requires certain functionalities for the moving walk structure. Where the standard is not providing needed answers literature is to be used to support the decisions. (EN 115-1, 2010)

Development of the design is done as an iterative process, repeating the actions done in creativity and judgment step. Value analysis process can be used concurrently with other engineering methods. Engineering tools presented later in chapter 2.3 are used in developing the final solution. Goal for the development step is that the designed solution is in compliance with EN 115-1 standard and that functionality of the solutions is also verified. (EN 12973, 2000, p. 25)

2.2.6 Finalizing the design and presentation step

According to the knowledge learned in prototype tests and iteration activities the final optimal design is created. Needed calculations and tests are done to ensure that the modified components are compatible with the safety standard and also that the structure meets required needs set in information step.

The final results are presented in this step. The value that the solution gives is calculated and compared to the original solution. According to this step potentiality of a business case can be reviewed and decision for implementing the design can be done. (EN 12973, 2000, p. 40)

2.3 Other Engineering Methods

Other engineering methodologies besides value analysis are also to be used to get wider perspective to the design work. The chosen tools are design for manufacture and assembly (DFMA) and modular design. The methodologies of these tools are especially applied in the creativity step in the job plan of the value analysis.(Miles, 1989)

InnoTrack^{TM} uses modules to enable configurable structure. Device is assembled on site which sets certain challenges for the components. Manufacturability of the components defines the accuracy for tolerances which are related to installation. According to these attributes it is logical to use DFMA and modular design to improve the value of InnoTrack^{TM}. Modular design and DFMA share the same goal for cost savings and adding quality to the product which inevitably increases the value of a product. (Boothroyd, 2002, pp. 1-8; Gerhenson & Prasad, 1997)

2.3.1 Design for Manufacture and Assembly

Product designer has a responsibility to take account the aspects of manufacturability and install ability. These aspects will be considered during the design process. The main goals for DFMA are: need to simplify the product and its manufacturing, improve the integration between design and manufacturing and increase productivity. Results from use of DFMA methodology are usually cost savings which come from increased quality, saved time and improved manufacturing process. (Eskelinen & Ström, 2007)

In case of InnoTrack^{TM} the assembly time impacts highly to overall costs. It is important to embrace that unlike conventional moving walk InnoTrack^{TM} is assembled on site. Basic sites for moving walk are airports and train stations, where there is no possibility to use same equipments as in the factory. In this master thesis following guidelines are to be followed to reach the DFMA goals. (KONE Corporation d, 2011)

1) *Minimize the number of components:* Usually the number of components inflects negatively to the assembly time. Modular constructions or parts with many functions are to be considered in design stage.

2) *Design simple assembly sequences:* In manual assembly simple steps are easier to carry out which will also reduce assembly time. Additional joining components should be avoided.
3) *Use symmetrical parts and parts that can't be installed wrong:* These rules simplify the installation process and also reduce the risk for mistakes. Parts that have end-to-end symmetry and rotational symmetry about the axis of insertion are usually easier to install. If full symmetry can't be achieved, design the maximum possible symmetry.
4) *Built in layers:* If it is possible design the structure so that each part can be installed from above or from same direction. Prevent the necessity for holding parts down to maintain their orientation. Design features that will prevent jamming of the parts that tend to nest or stack. Leave space for tools during the assembly.
5) *Simple manufacturing process:* Complex manufacturing process inflects to the price. It can be justified in some cases but the value should be then high for this component. Minimize the number of different manufacturing processes. Rules of easy manufacturing are to be obeyed.
6) *Use common materials:* Common materials are available globally and the prices are usually more stable than rare materials.
7) *Use standardized geometry, part and tools:* Usually commercial components are cheaper than self-designed. Standardized geometry will ensure that design is feasible to manufacture and there is suppliers that can do it easily.(Boothroyd, 2002, pp. 89, 125-127, 210-211; Eskelinen & Ström, 2007)

2.3.2 Modular design

According to Karl Ulrich, *"Modularity arises from the division of a product into independent components. This independence allows a firm to standardize components and to create product variety."* (Ulrich, 1994)

A product which is divided to smaller functional groups is called modular product. These groups have clear interfaces which are to be kept same. The idea behind modular design is that modules can be used independently and also in different structures just like Ulrich K. says. Consequently each module can be modified and improved without effecting highly on the whole product. The use of same module in different structures brings up the volumes and usually then manufacturing costs are lower for one component. In contrary integrated structure have components that are optimized to perform in the best possible way. In a modular structure there are always compromises due to the interfaces between the modules. (Gerhenson & Prasad, 1997)

Overall structure and modules in InnoTrack^{TM} are however different from conventional ones. This thesis work focuses on modifying an exciting module and its connection interfaces. Target is to study the modularity level inside of the middle section module and use this study to support the decisions in the design work.(KONE Corporation d, 2011)

3 VALUE ANALYSIS

3.1 Original solution and customer needs

The main component groups of InnoTrack™ are shown in figure 4. CombiRail™ truss (1) is the main structure of the device. Drive machinery (2) is composed of the PowerDisk™ (3) motor and belt operated drive system OptiDrive™ (4). Pallets (5) and pallet chain (6) form the pallet band. Handrail (7) provides a handhold for passengers and travels around the balustrade in sync with the pallet band. Pallet reversing station ThinReverser™ (8) is the turnaround station for pallet band. Pallets are reversed without turning they are directed under the stepping surface and lifted up on the other end. Balustrade consists of skirts (9), deckings (10) and glass balustrade (11). The structure leading to the pallet band is called ramp (12). The controller controls and monitors operation of the unit is placed under the ramp. Both landings have a combplate (13) where passengers enter and exit pallet band. (KONE Corporation d, 2011, pp. 26-27)

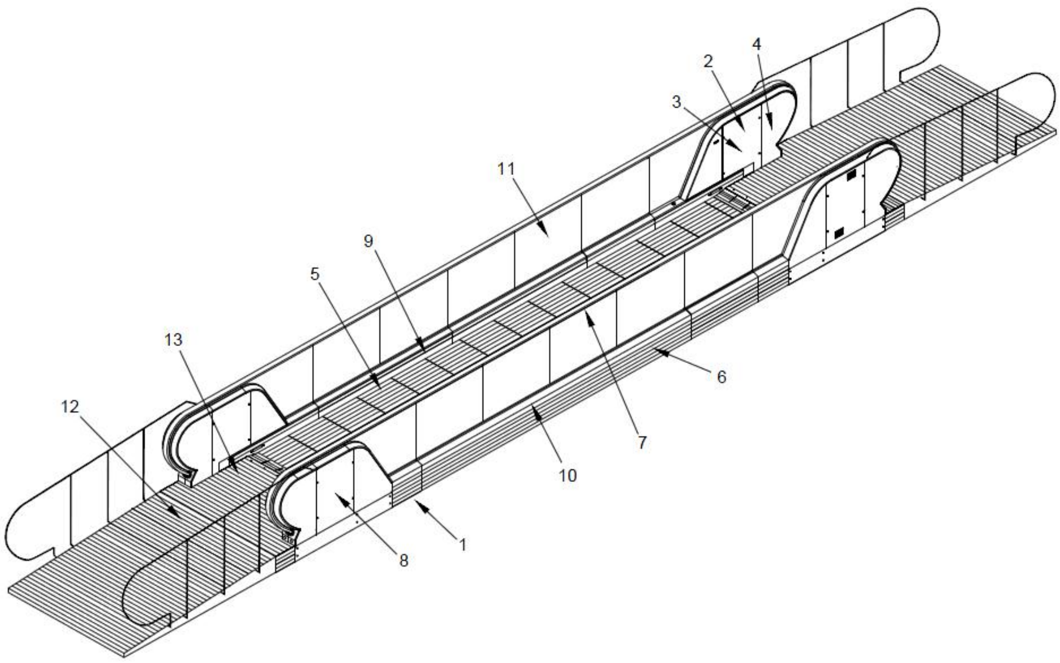


Figure 4. InnoTrack™ product structure - original design (KONE Corporation d, 2011, p. 27)

Cross section of an InnoTrack™ middle section module is presented in figure 5. The structure is divided to five sub modules. These modules are: truss module, middle section material module, crossbeam packages type 1400, glass panel for middle section and handrail guide profile module.

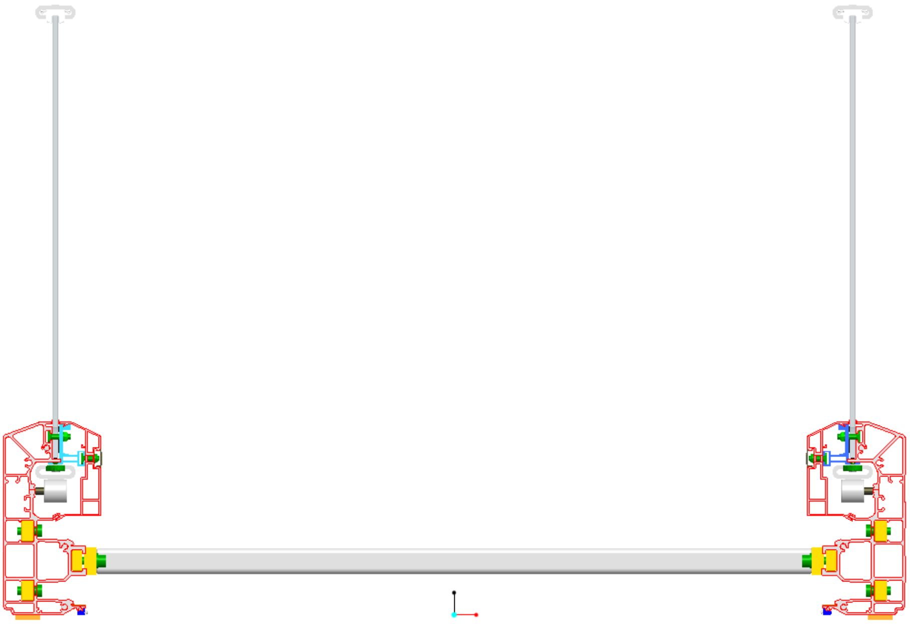


Figure 5. InnoTrack™ cross section of middle section module - original design

Principle for connecting different modules can be seen in figure 6. Steel blocks are used to fix sequential aluminum truss profiles. Cross beam is located at the split area. The cross beam is third connection between two aluminum profiles and pressure plate is forth as it is installed also at the split area. Pressure plate fastens the balustrade glass and provides fixing point to skirting profile.

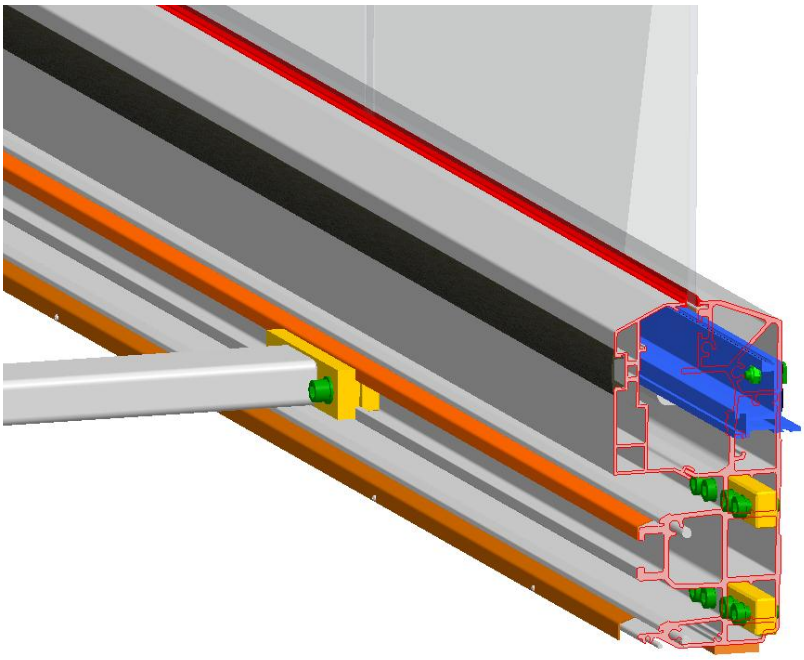


Figure 6. InnoTrack™ middle section connection - original design

The extruded aluminum truss profile is also mounted to drive and tension head modules. Due to this design the head modules use same connection principle as two middle section modules. Tension head module is presented in figure 7.

Escalators and moving walks have usually a tension head which makes sure that the pallet band chain has right tension. Chain sprocket assembly is a floating system. It is adjusted to right position and structure is tensioned with springs. Due to this design there must be a special split area which enables adjustment for the floating track and provides continuity despite the different positions of the chain sprocket. In original design for InnoTrack™ this split area is mounted to the aluminum profile and can be seen from the figure 7.

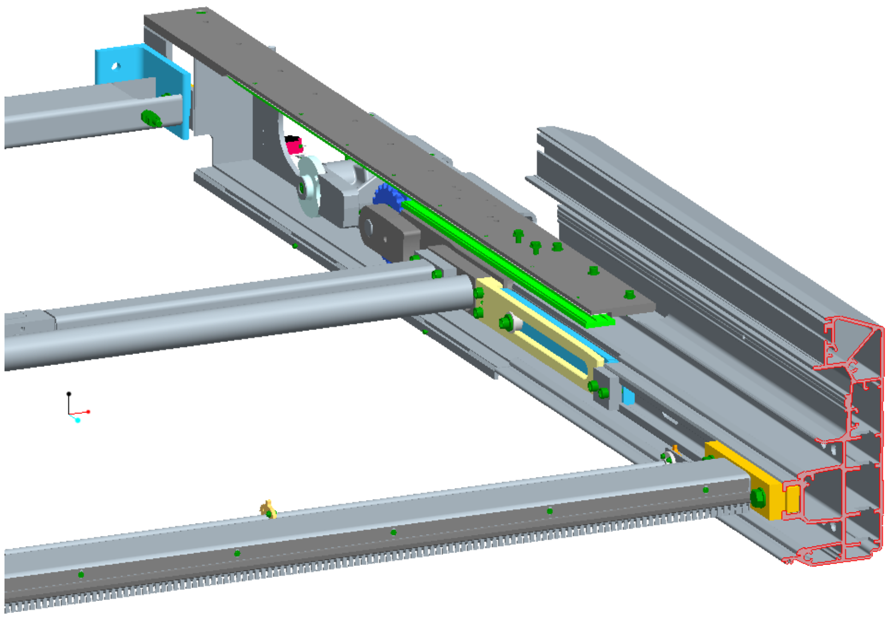


Figure 7. InnoTrack™ tension head module – original design

3.1.1 Design background and objectives

Idea behind original design is to integrate different functions to the extruded aluminum profile. Aluminum profile is at the same time the load carrying truss, upper and lower pallet roller track, glass holder, handrail guide and visual component. The aluminum profile is simple from design point of view and as it integrates lot of functions it provides basis for easy installation.(KONE Corporation c, 2011)

According to the closing report of the InnoTrack™ the unit design is generally verified by thorough testing and validated in the field. Basic functionality and reliability is achieved and root causes for problems encountered in field are well understood and documented. InnoTrack™ was released and the first units were sold before the design had been thoroughly validated. This can be said to cause lot of problems in the pilot units which were delivered to Schiphol airport in Amsterdam. (KONE Corporation c, 2011)

Overall design carries the whole development history. Project was pushed to end and extruded aluminum truss profile was used instead of considering other options. Current design for extruded aluminum profile is limiting the options to develop head sections. This is because all functions are depending on profile and without re-designing this profile it is challenging to improve head sections. (KONE Corporation c, 2011)

Project objective for InnoTrack^{TM} was to design flat autowalk and achieve required level of reliability. Business targets were set in level of yearly volume. InnoTrack^{TM} project was closed in 2011 when business case targets were not achieved. Due to the low number of sold units call out rate is nearly three times higher than the target. (KONE Corporation c, 2011)

Original solution, cost model

Complete cost model for original InnoTrack^{TM} has 17 different modules. Ten of these modules are depending on the length of the unit. This means that cost model varies when the length of the unit changes. Length of the studied unit is 48 meters and nominal width of the pallets is 1.4 meters. Value of single middle section module is not depending on the length of the unit. Total costs of middle section modules are 20 % from the complete unit in this studied case. Cost model for complete unit is presented in appendix 1.

As mentioned earlier middle section module of the InnoTrack^{TM} beholds five different sub modules. The cost model for one middle section module is presented in figure 8. Extruded aluminum profile is included to the truss module. This is the most expensive sub module inside of the middle section. Truss module beholds 59 % of costs in middle section module. Skirting profiles and glass support plates are included in the middle section material module and this is the second most expensive item in middle section module with 24 % share.

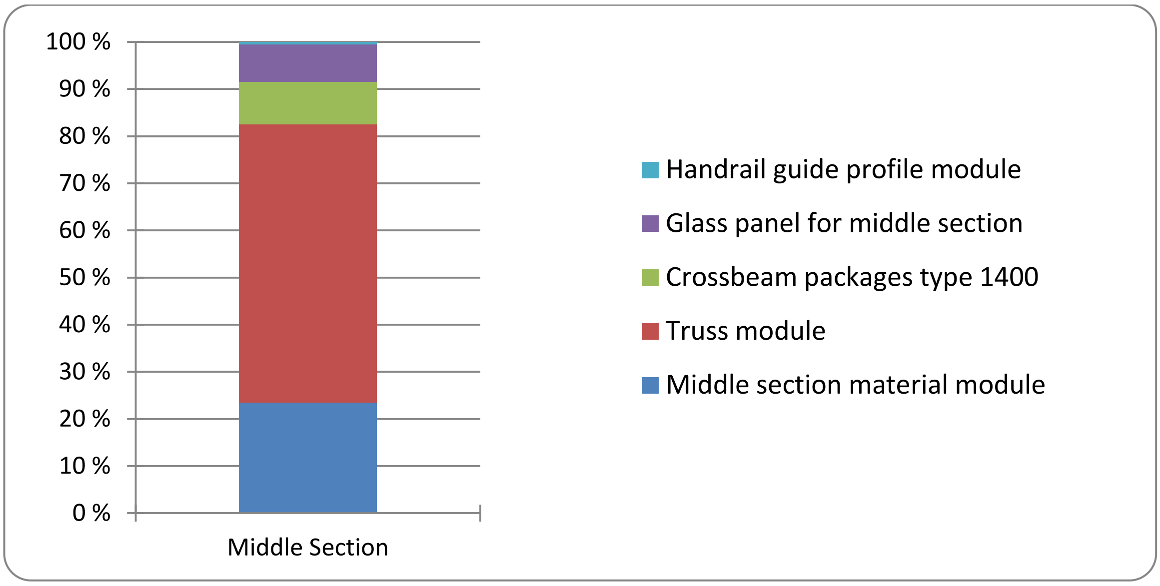


Figure 8. Cost model for middle section module original design

3.1.2 Customer needs for InnoTrack™

According to the information in KONE technology organization characters such as "installation without a pit" and "possibility to move or modify length of the unit" are still desirable for customers. InnoTrack™ is still arousing interest among customers. This interest is lost when unit price is revealed. Despite the low number of sold units and almost nonexistent yearly volume of InnoTrack™ it is believed that there are still potential markets for flat moving walks. Current InnoTrack™ is not giving enough value to the customer and the reason is clear, unit price is too high. Compared to a conventional KONE moving walk AJV InnoTrack™ is 5.7 times more expensive. (KONE Corporation c, 2011)

According to this information it can be concluded that original characters of InnoTrack™ are fulfilling the customer needs. Customer needs are presented in table 2. The needs are transformed from the characters of original InnoTrack™. Each need has listed objective to provide understanding for the reason of the need. Customer needs are limited to consider only middle section module according to the scope of this thesis.

Table 2: Customer needs

Customer needs	Objective
Compatibility with EN 115	Design must meet the safety requirements of EN 115
Configurable unit	Unit can be moved and reinstalled Unit length can be modified
Light weight	Possibility to install the unit on a finished floor Installation without a pit
Space efficient solution	Low ride height All components are inside of the unit
Easy to assemble	Fast installation time
Fine ride comfort	Smooth and silent ride along the unit
Appealing visual appearance	To provide desirable appearance with visual components, materials and shape

3.2 Required functions for InnoTrack™

Required functions are based on the customer needs and their objectives. Each need has a weighted value to show the importance of the function. Needed functions and weighted values are shown in table 3. Customer need is always depending on the customer. The focus on developing the new solution for InnoTrack™ middle section is in safety. If the design doesn’t meet the requirements in safety standard it can’t be sold. Weighted value of meeting code requirements is 50 %. By meeting code requirements it can be proven that the unit is safe for human transportation. Each remaining need has equal 10 % share.

Table 3: Required functions and their weighted values

	Required function	%
1	Meet the EN 115 code requirements - where applicable for middle section	50
2	Allow installation on finished floor	10
3	Provide fine ride comfort	10
4	Allow configurable unit	10
5	Allow easy maintenance	10
6	Provide pleasing appearance	10

Required functions are divided to sub functions and these are presented in appendix 2 by using value trees. Function groups are based on required functions and their sub functions. Each function group has a defined task. By fulfilling these tasks the solution will give satisfaction to customer's needs. The weighted value of each required function is taken account when selecting function groups and their tasks. Function groups and their tasks are presented in table 4.

Table 4: Function groups and their tasks

	Function group	Task
1	Supporting structure	Carry rated load Enable flat design Enable easy installation → Interface between the floor
2	Roller tracks	Carry load on pallets Guide pallets
3	Balustrade	Carry balustrade load Enable easy installation
4	Handrail guiding system	Enable handrail guiding Allow replacement of the handrail → Maintenance
5	Visual panels	Carry skirting load Carry outer loads Allow maintenance for replaceable components Provide pleasing appearance
6	Module connection	Enable continuity over modules Enable easy installation → Interface between modules

3.2.1 Original solution, satisfaction of needs current costs

Original solution is analyzed to gather understanding how the original solution fulfills the customer needs and tasks set for each function group. This analysis is presented in appendix 1 and it is used to judge how the function group tasks are accomplished in middle section module of the original InnoTrack™. Based on the analysis each function group is then graded by author. The scale for grades is from one to ten and results are presented in table 5.

Table 5: Original solution, satisfaction of needs

Function group	Grade
Supporting structure	3.0
Roller Tracks	6.0
Balustrade	6.0
Handrail guiding system	8.0
Visual panels	4.0
Module connection	7.0
Average	5.667

The cost of each function group is presented in figure 9. The sum of function group costs is same as previously presented costs of different modules in original middle section. Extruded aluminum truss profile is intergraded structure and it enables tasks in each function group. The costs of the profile are therefore divided into shares between function groups.

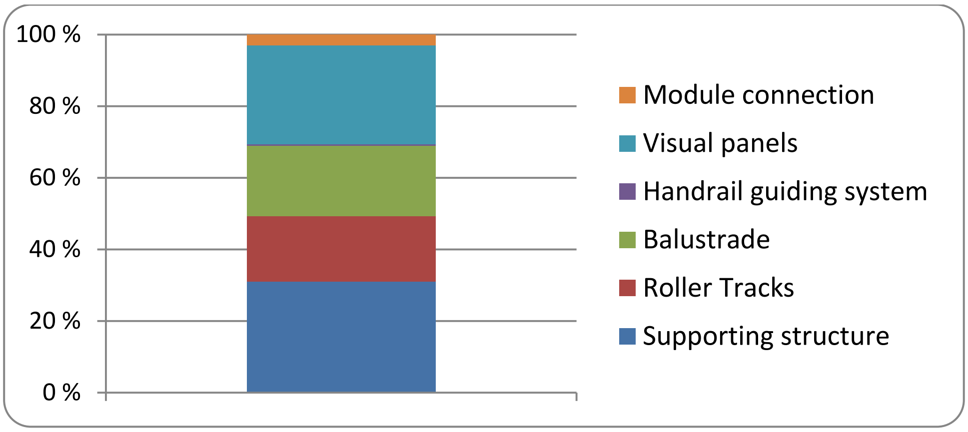


Figure 9. Function group costs - original design

3.3 Created solutions

New solutions are designed with 3D design tool Pro ENGINEER Wildfire 4.0 2008. AutoCAD 2008 B.219.0 (UNICODE) is also used in creativity step to help the designing process. In creativity step calculations are done analytically or with a Mechanica tool in Pro Engineer Wildfire 4.0. Mechanica tool is a built in FEM tool and it creates only light calculation models. In this thesis work Mechanica tool is used to study the feasibility of new solutions. Calculation models created with Mechanica tool have solid tetra elements with 3 degrees of freedom. Elements are created with auto mesh tool as Mechanica tool doesn't support any other ways to create solid elements.

Three new solutions are designed for InnoTrack™ middle section. Each design is created by using earlier defined function groups. New solutions have all same nominal unit width of 1400 mm. Solutions are designed to work also in a unit with nominal width of 1000 mm or 1200 mm. Cost of each solution is presented as a metric value compared to the original cost. Basis for each design is presented in following chapters. Created solutions are then introduced according to the function groups.

3.3.1 Introduction of new solutions

Solution 1, reduced aluminum truss profile

Idea is to reduce the size of the aluminum truss profile. Smaller profile is manufacturing friendlier and uses less aluminum. Reduced aluminum truss enables certain functions and other functions are carried out with new components. Length of one module is 4064 mm which is same as the original. Weight of one middle section module is 620 kg. Solution 1 is presented in figure 10.

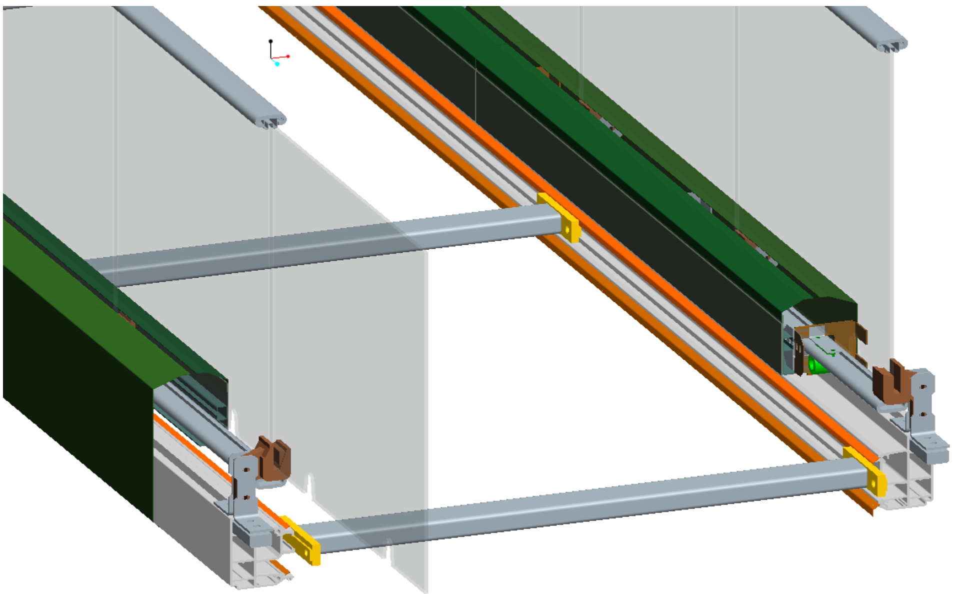


Figure 10. Solution 1, reduced aluminum truss profile

Solution 2, roll formed steel combitrack

Idea in solution 2 is to replace the aluminum profile with roll formed steel profile. This profile guides upper and lower roller tracks in one side. Roll formed steel profile is fixed to number of multipurpose brackets. Brackets are standing on the floor with integrated foot. Foot height can be adjusted. Length of one module is 4064 mm and it weighs 590 kg. Solution 2 is shown in figure 11.

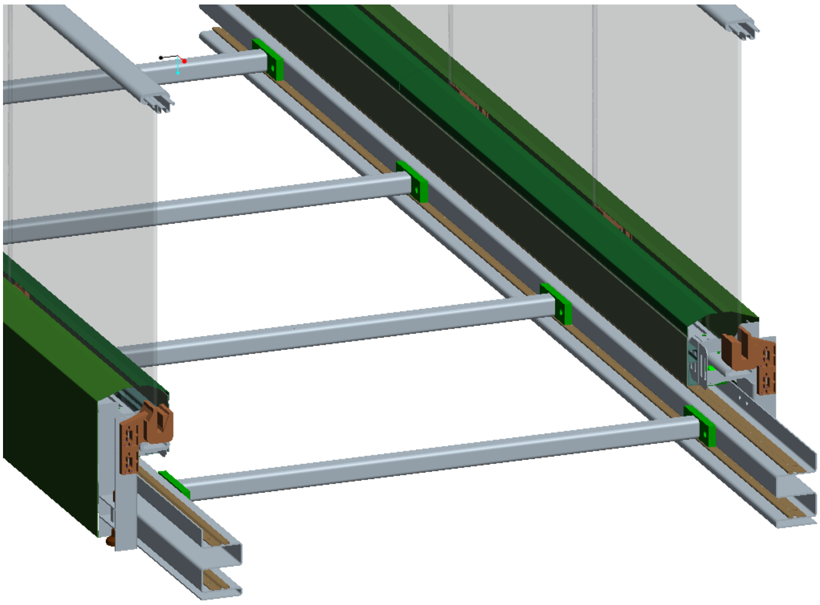


Figure 11. Solution 2, roll formed steel combitrack

Solution 3, self-supporting bracket system

Solution 3 uses self-supporting brackets to carry all necessary components. The implementation of this idea is basically same as in solution 2 but instead of roll-formed profile the roller tracks are separate pipe profiles. This approach is similar like in conventional moving walks. Conventional autowalk uses multipurpose brackets to support guide rails, handrail guiding system and skirting. In this solution also glass holder is fixed to the bracket. Instead of fixing the bracket to truss it is self-supporting and standing on a foot. Foot is adjustable pad like in solution 2. Length of one module is 4064 mm and weight is 600 kg. Solution 3 is shown in figure 12.

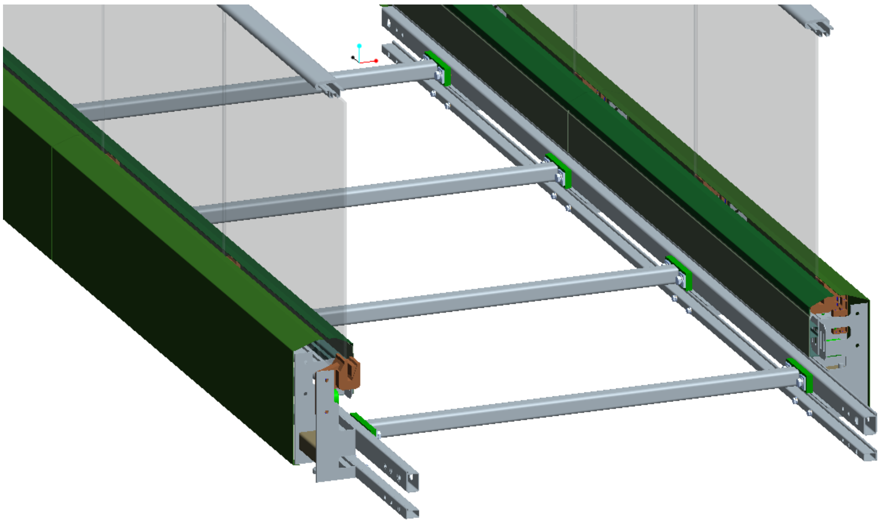


Figure 12. Solution 3, self-supporting bracket system for moving walk

3.3.2 Supporting structure

Solution 1, supporting structure

Extruded aluminum profile works as a supporting structure in solution 1. Profile works in same principle as original design. Left and right side are connected to each other with cross beams. Cross beam design is same as in original. The cross section area of the reduced aluminum profile is 61.3% from original design. Cross-section of the supporting structure is presented in figure 13.

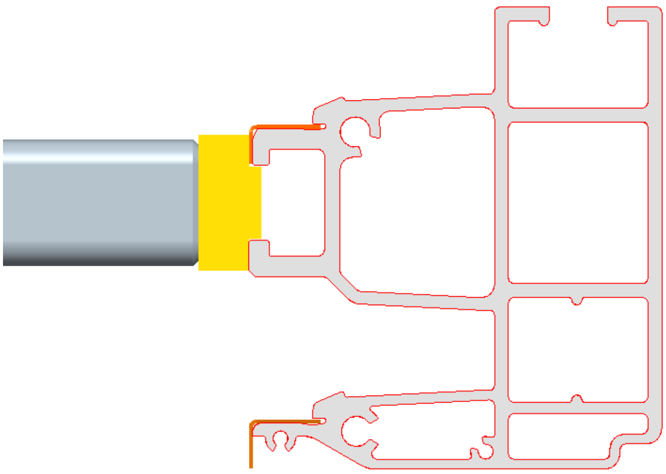


Figure 13. Solution 1, supporting structure

Reduced aluminum profile has to carry the rated load and dead weight of the structure. Load carrying structure is basically same as in original design. Structural analysis calculations are available for original design. Inertia of the new design is different due to the reduced height of the profile. Displacement of the aluminum profile is calculated analytically by using beam theory. Calculations are presented in appendix 4. Displacement on the middle of the profile is calculated to be 2.28mm, allowable displacement is 5.48 mm.

Fixing interface on top of the aluminum profile can be seen in previous figure 13. Interface is basically an integrated C-profile. The C-profile carries the balustrade load and skirting load. Material thicknesses are copied from original and are assumed to be strong enough to carry same loads.

Solution 2, supporting structure

The supporting structure of the solution 2 has three main components: cross beams, roller track profiles and supporting brackets. Cross beams are linked to the roller tracks which are fixed to brackets. There are totally eight brackets and each of them has an adjustable foot. Span between the brackets in longitudinal direction is 1012 mm. Brackets are bended sheet metal components. Brackets and combirails are manufactured from steel. Load carrying structure is presented in figure 14.

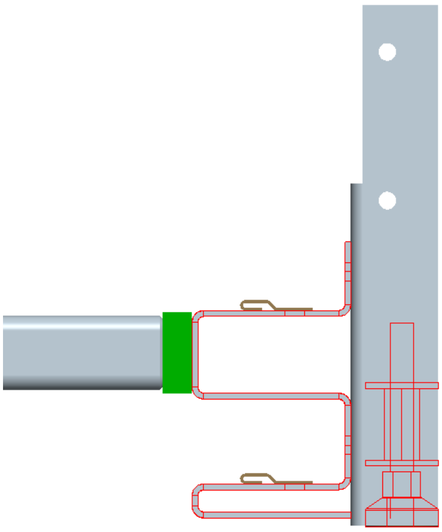


Figure 14. Solution 2, supporting structure

The load carrying structure for solution 2 is calculated with PRO/Engineer Mechanica tool. The calculation model is introduced in appendix 4. The highest stress occurs in point between fixing nut of adjustable pad and bracket plate. Stress value is 418 MPa. This high stress value occurs inside of two elements. It is likely that the stress value is high due to the singularity of the model. Generally the stresses are less than 180 MPa. Detailed results from stress calculation are shown also in appendix 4. The biggest displacement occurs in the middle of the cross beam and the value is 1.304 mm. Results from displacement calculation are also shown in appendix 4.

Solution 3, supporting structure

Supporting structure of the solution 3 has also three main components: cross beams, roller tracks and brackets. All components are manufactured from steel. Brackets are bended sheet metal components and span between two brackets in longitudinal direction is 1012 mm. Supporting structure is presented in figure 14.

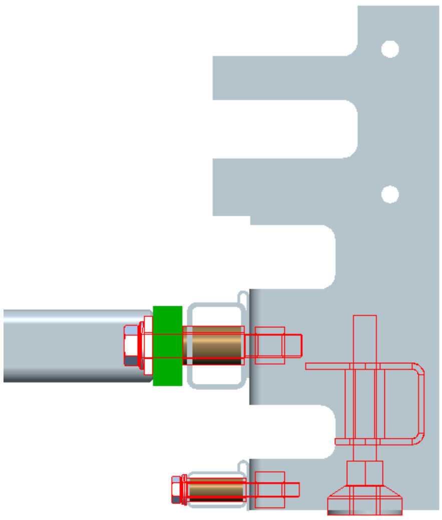


Figure 15. Solution 3, supporting structure

The load carrying structure is calculated with PRO/Engineer Mechanica tool. The calculation model is introduced in appendix 4. The highest stress occurs in point between fixing nut of adjustable pad and bracket plate. The highest stress value is 214 MPa. This stress occurs inside of two elements but as the stress value is low it is likely that this stress is really occurring. Result from stress calculation is presented in appendix 4. Stress levels are generally under 180 MPa. The biggest displacement occurs in the middle of the cross beam and the value is 1.322 mm. Results from displacement calculation are presented in appendix 4.

3.3.3 Roller Tracks

Solution 1, roller tracks

Passenger and return side roller tracks are integrated to the aluminum profile in solution 1. The design for roller tracks is exactly the same as in original design. The design is verified and validated to be functional in the original unit. Roller tracks can be seen in previous figure 13.

Solution 2, roller tracks

In solution 2 passenger and return side roller tracks are integrated to the roll formed steel profile. Additional roll formed steel profiles will guide the pallets. Roll formed track profile and guides can be seen in previous figure 14. The guide is fixed to the roller support profile with rivets. Displacement of the roller track profile is calculated in appendix 4. According to the results the biggest displacement is less than 1.00 mm when rated load is applied.

Solution 3, roller tracks

Solution 3 uses standard rectangular steel hollow profiles as roller tracks. Both profiles are according to Chinese GB standard. Pallet guides are separate roll formed steel profiles. These profiles are fixed to the hollow profiles with rivets. Upper and lower roller track are fixed to the brackets with screws. Round bushings are inserted inside of the roller track profile to prevent deformations on the running surface of the track. These roller track profiles can be seen in previous figure 15. According to the calculation the displacement of the upper roller track is less than 0.7 mm when rated load is applied. Displacement results for upper roller track can be seen from appendix 4.

3.3.4 Balustrade

Solution 1, balustrade

Balustrade glass in solution 1 is fixed with glass holder. Glass holder is a die cast component manufactured from aluminum. Base structure of the glass holder is copied from existing design used in other conventional escalators and autowalks. Glass holder is fixed into two sheet metal plates and these plates are fixed to the aluminum profile with help of a steel block. Design for glass holders and their fixings are presented figure 16.

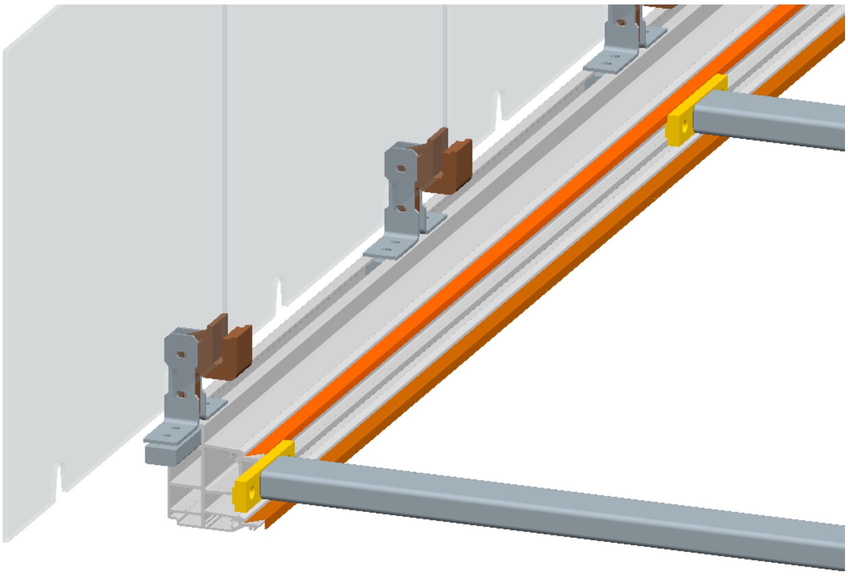


Figure 16. Solution 1, balustrade design

Solution 2, balustrade

Solution 2 uses the same design for glass holder as solution 1. The glass holder is fixed to the supporting bracket with screws. Design is presented in figure 17. Supporting bracket will carry the loads from balustrade. Strength of the bracket is calculated with PRO/Engineer Mechanica. Calculation model is presented in appendix 4. The highest stress occurs in the sharp corner of the bracket and the value is 746 MPA. The stress peak is inside of two elements and the high value is likely to be result from the singularity of the calculation model. From the results it can be seen that the stresses in bracket are close to the yield stress limit of 235 MPa. Areas close to the sharp corner and on the other side are under the biggest stress and stress values go over the yield stress level. The biggest displacement occurs in the middle of the free end of the bracket and the value is 1.75 mm. Results from displacement calculations are presented in appendix 4.

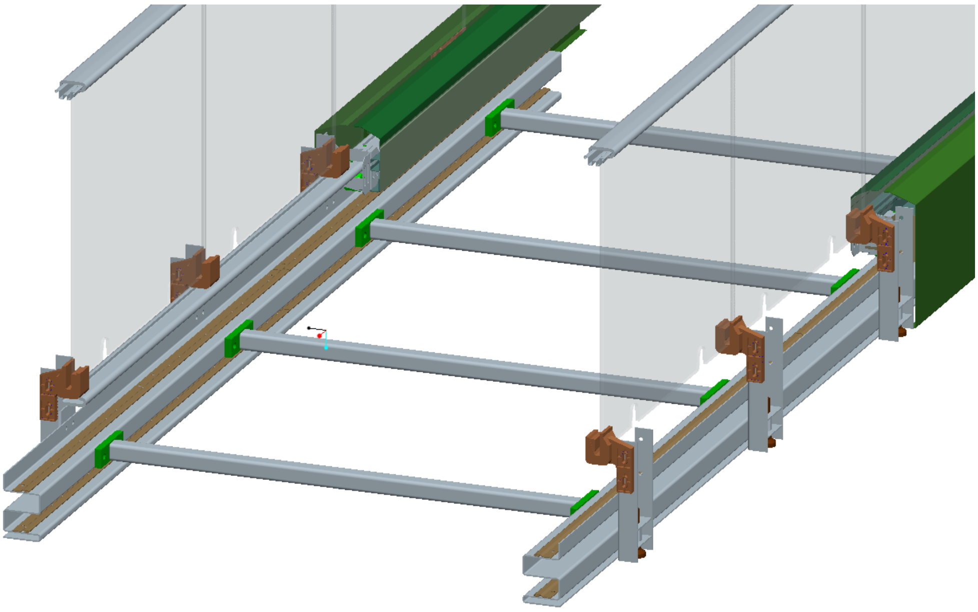


Figure 17. Solution 2, balustrade design

Solution 3, balustrade

Solution 3 uses also the same glass holder as solutions 1 and 2. The glass holder is fixed to the supporting bracket with screws. Supporting bracket will carry the load from handrail. Balustrade design for the solution 3 is presented in figure 18. Strength of the bracket is calculated with PRO/Engineer Mechanica tool. Calculation model is presented in appendix 4. The highest stress occurs in the corner of the bracket and the value is 695.5 MPA. The stress peak is inside of two elements and it is likely to be result from singularity of calculations model. From the results it can be seen that despite the previously mentioned stress peak the stresses are generally less than 235 MPa. The stresses however rise close to the stress limit. The biggest displacement occurs in the middle of the free end of the bracket and value is 1.75 mm. Results from displacement calculation are presented in appendix 4.

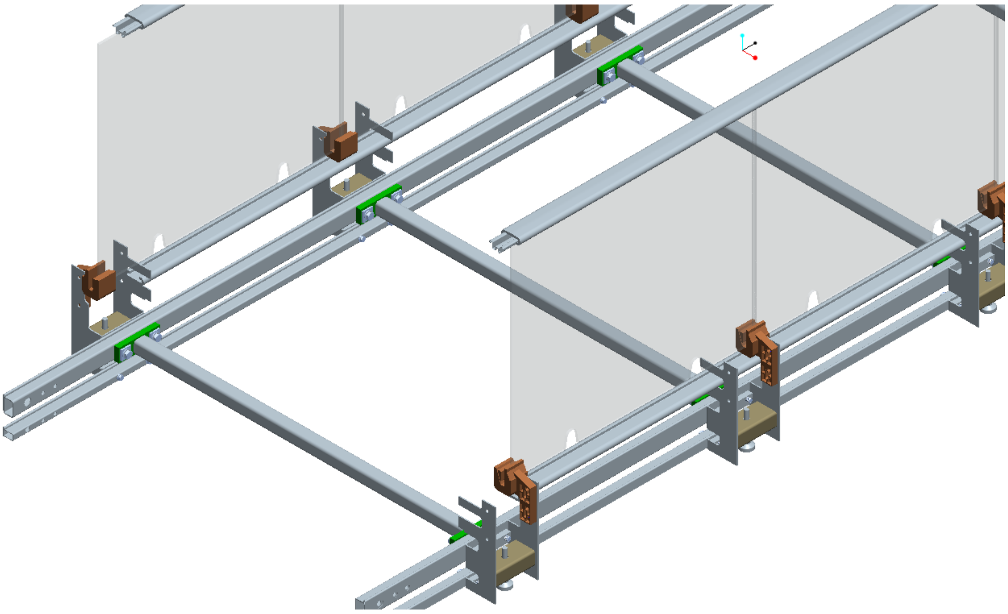


Figure 18. Solution 3, balustrade design

3.3.5 Handrail guiding system

Solution 1, handrail guiding system

Design for handrail guiding in solution 1 uses same components as the conventional KONE autowalks and escalators. On passenger side the handrail slides on top of the balustrade. Sliding profile is same as in conventional KONE autowalks. On return side handrail is guided with bearing and support roller. Guiding system is fixed with steel plate to the aluminum profile. This handrail guiding bracket is presented in figure 19. Design for the skirting support doesn’t allow replacement of the handrail without removing the skirting panel.

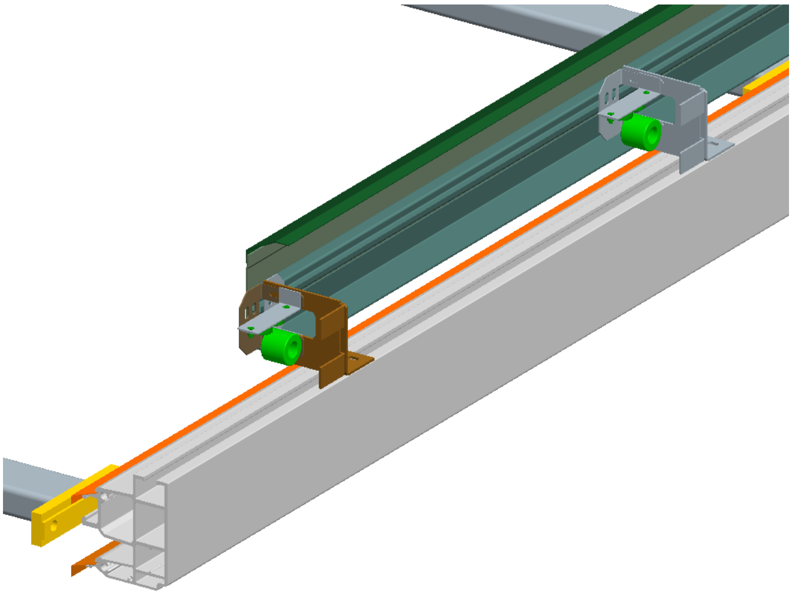


Figure 19. Solution 1, handrail guiding system and fixings for visual panels

Solution 2, handrail guiding system

Solution 2 uses basically same design to guide handrail as solution 1. On passenger side the handrail slides on top of the balustrade and on return side handrail is guided with bearings and support roller. Like in solution 1 the skirting needs to be re moved when handrail is replaced. Fixing of the handrail guide is presented in figure 20.

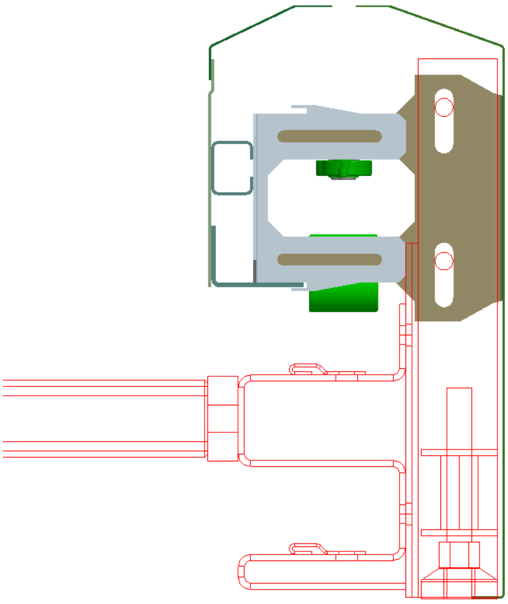


Figure 20. Solution 2, handrail guiding system and fixings for visual panels

Solution 3, handrail guiding system

For solution 3 the guiding system is following the same design as the solutions 1 and 2. The fixing plates are slightly different and they are presented in figure 21

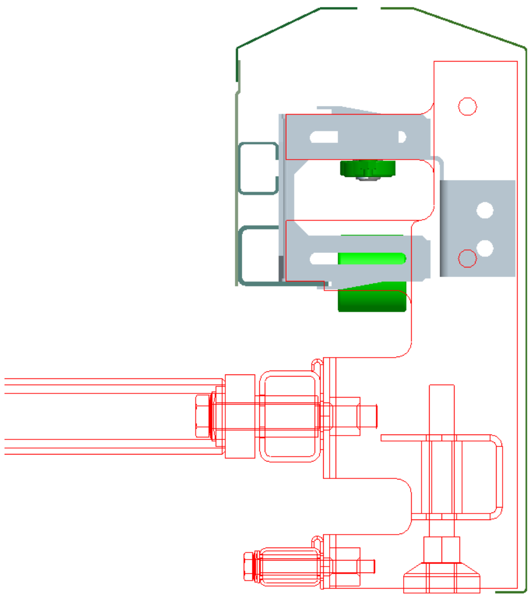


Figure 21. Solution 3, handrail guiding system and fixings for visual panels

3.3.6 Visual components

Solution 1, visual components

Skirting, cladding, inner and outer decking are fixed to the same steel bracket as handrail guiding system. The relevant components are manufactured from sheet metal plates. Visual parts are from stainless steel and non-visual are from carbon steel. Skirting and inner decking for solution 1 are presented in previous figure 19.

Design principle for visual components is copied from conventional solutions. Skirting material thickness is same as in conventional KONE unit and span between support points is 1012 mm. The skirting profile displacement is calculated with PRO/Engineer Mechanica tool. Calculation model is presented in appendix 4. When applying the required load of 1500 N the biggest displacement is 3.470 mm. The calculation results are presented also in appendix 4. Material thickness of other visual sheet metal components is 1.5 mm which has been found strong enough in other KONE autowalk and escalator products.

Solution 2, visual components

For solution 2 skirting, cladding, inner and outer decking are fixed to the supporting bracket. Design is equal with solution 1 except the fixing plates are slightly different. Fixing bracket is presented in previous figure 20. Due to the similar design as in solution 1 it is assumed that the skirting design in solution 2 will carry the required load.

Solution 3, visual components

In solution 3 skirting, cladding, inner and outer decking are fixed also to the supporting bracket. Fixing is done with number of fixing plates. All fixing plates are bended sheet metal components. Excluding the fixing plates the design is equal with the solutions 1 and 2. It is assumed that the design full fills the code requirements as calculated in appendix 4. Fixing of the visual components in solution 3 is presented in previous figure 21.

3.3.7 Module connection

Solution 1, module connection

Module connection between two middle sections in solution 1 is in principle same as in original solution. Aluminum profile has one connection block and the glass holder will work as a second fixing block. Aluminum profile has pins to keep the profile in right position and help the installation. Like in original design the cross beam is fixed in the interface between the modules. Connection between two middle section modules is presented in figure 22.

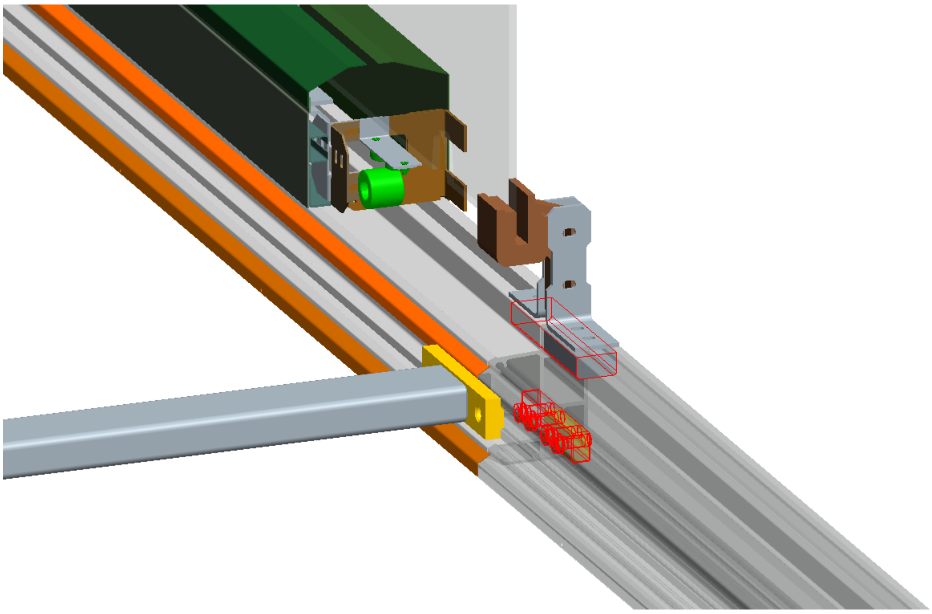


Figure 22. Solution 1, connection between two middle section modules

Both head sections have integrated part of the aluminum profile like in original design. Drive head has a steel frame and the aluminum profile is fixed to it with connection blocks. Tension head has also a steel frame and the aluminum profile fixed with connection blocks like in original design. Aluminum profile is not carrying any external loads in drive or in tension head. Therefore the design is considered to be feasible and in compliance with safety standard EN 115-1.

Solution 2, module connection

Roll formed profiles are connected to each other by using machined steel connection blocks. Connection interface is presented in figure 23. Connection requires high tolerance from roll formed profile. The running tracks needs to be always in same height.

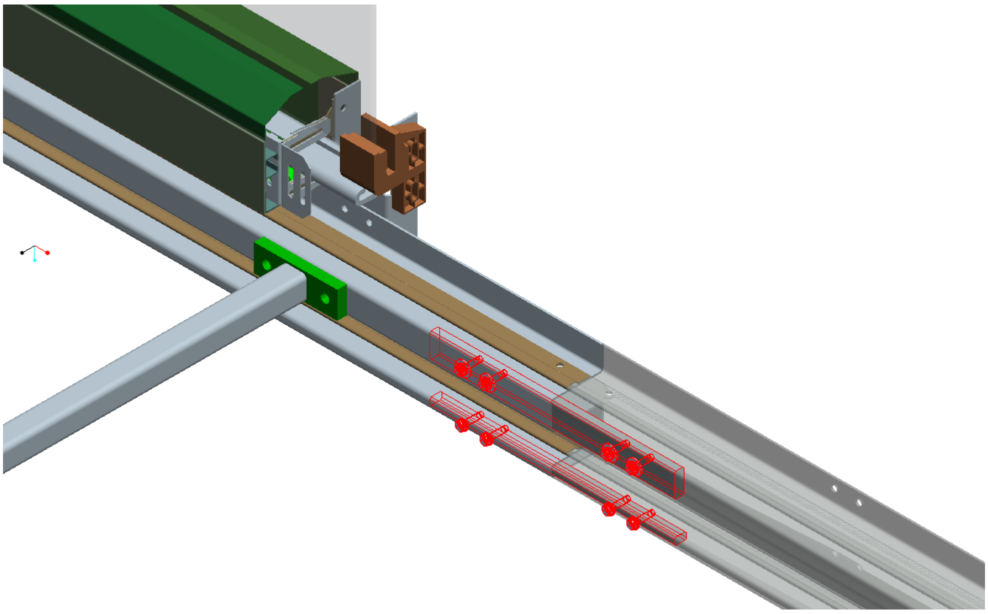


Figure 23. Solution 2, connection between two middle section modules

For solution 2 the head sections require certain modifications to provide connection for middle section module. The steel frame of the drive head is extended so that the roll formed profile can be fixed from side. In tension head the steel frame is extended in a way that the floating sprocket structure is inside of the frame. This is different compared to the original design and solution 1. With this design middle section is just fixed to the end of the steel frame. Design to fix tension head module connection to roll formed steel combitrack is presented in figure 24.

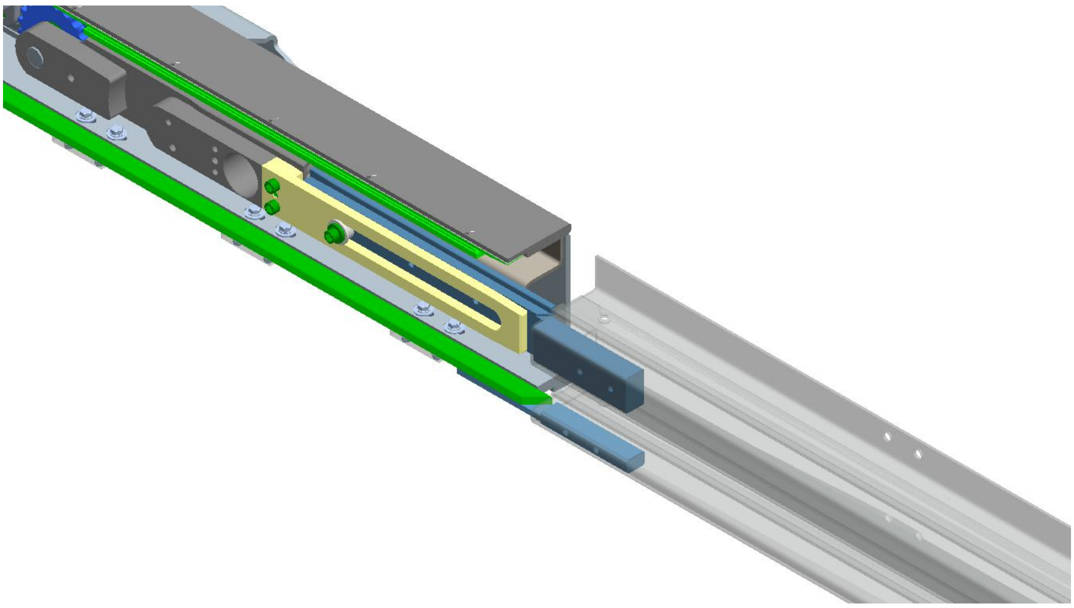


Figure 24. Solution 2, tension head module connection to roll formed steel combitrack

Solution 3, module connection

Solution 3 uses machined steel blocks to connect two middle sections with each other. These blocks are inserted inside of the roller track profiles. The block is fixed with screws to the both roller tracks. Interface has a 45 degree angle to provide better ride comfort. Connection is presented in figure 25.

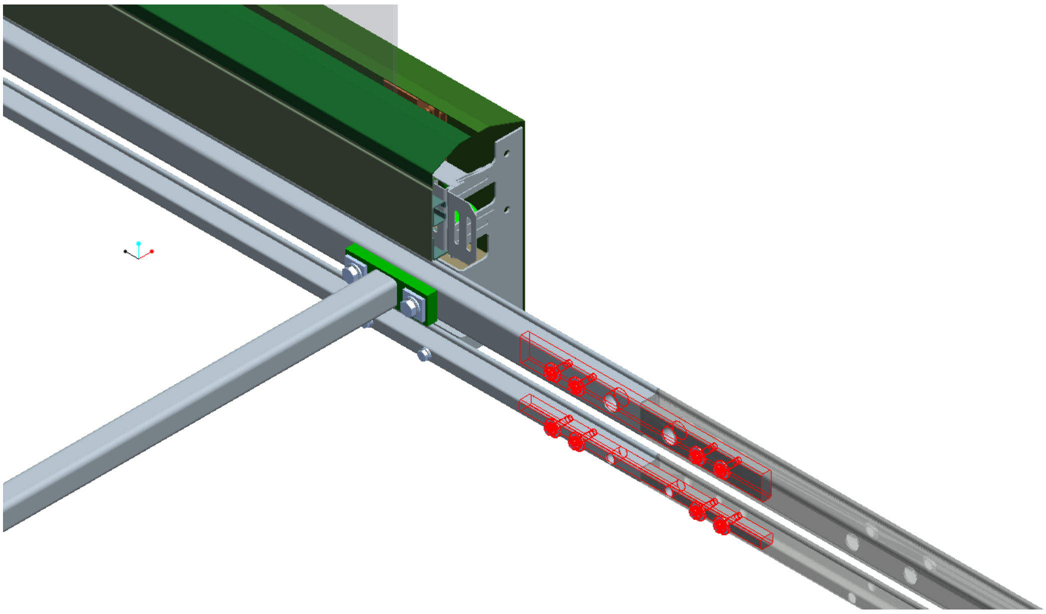


Figure 25. Solution 3, connection between two middle section modules

Middle section design in solution 3 has separate roller tracks and to fix these tracks to drive head there are four machined blocks. These blocks are providing the fixing interface between the modules. Connection between tension head and middle section follows the same idea to use steel blocks. The tension head steel frame is also extended. Due to the reason that roller tracks are separate profiles they are likely be in different positions respect to longitudinal direction. Therefore the lower track in tension head can be adjusted to match the lower track in middle section. Solution is presented in figure 26.

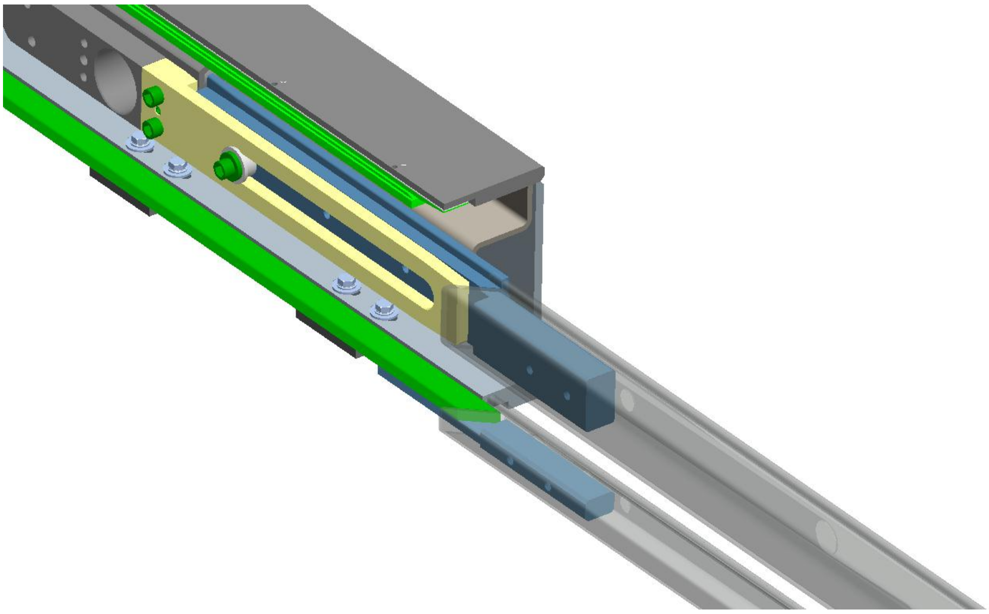


Figure 26. Solution 3, tension head module connection to roller track profiles

3.3.8 Value provided by created solutions

Created solutions, satisfaction of needs

All function groups for different solutions are graded by the author. These grades are given according to the listed advantages and disadvantages in appendix 5. The scale for grades is from one to ten. Grades have been given in terms of how well the function group fulfills needed tasks. The grades for each solution are presented in table 6. According to the average grade the solution 3 provides the best satisfaction to the customer's needs.

Table 6: Created solutions, satisfaction of needs

Function group	Original	Solution 1	Solution 2	Solution 3
Supporting structure	3,0	4,0	7,0	9,0
Roller Tracks	6,0	6,0	7,0	9,0
Balustrade	5,0	4,0	4,0	4,0
Handrail guiding system	8,0	3,0	3,0	3,0
Visual panels	4,0	7,0	7,0	7,0
Module connection	7,0	6,0	5,0	7,0
Average grade	5,67	5,00	5,50	6.5

Created solutions, needed resources

Component costs for different solutions are compared to the original design. Cost model for each solution is presented in figure 27.

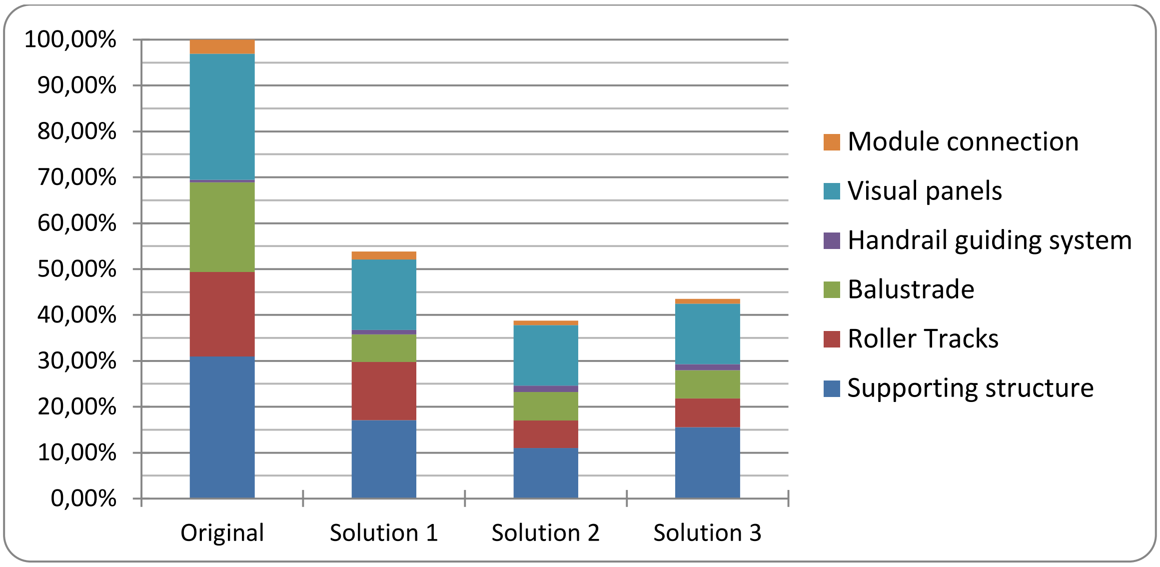
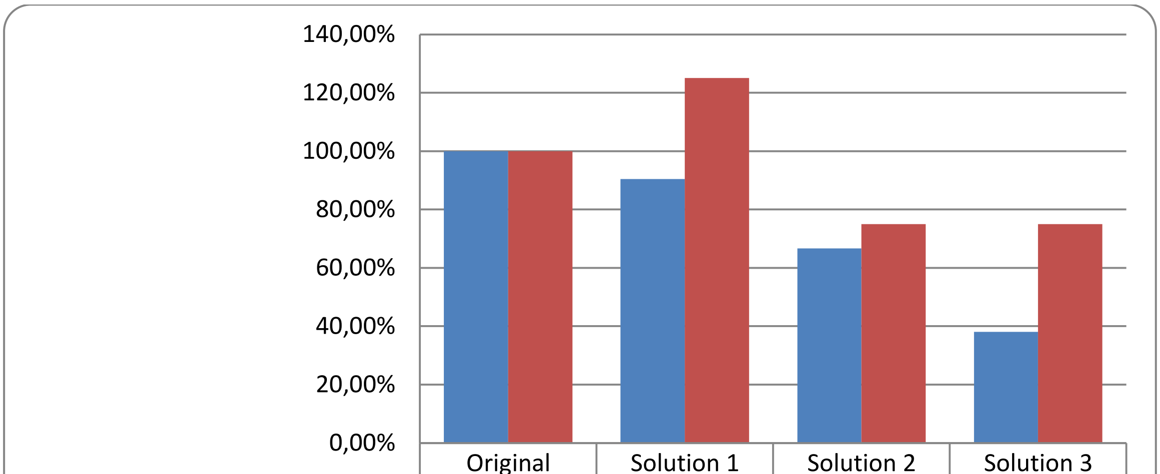


Figure 27. Cost model for created solutions

Costs differences between manufacturing tooling costs for created solutions are presented in figure 28. Assumptions for the installation time are presented also in figure 28.

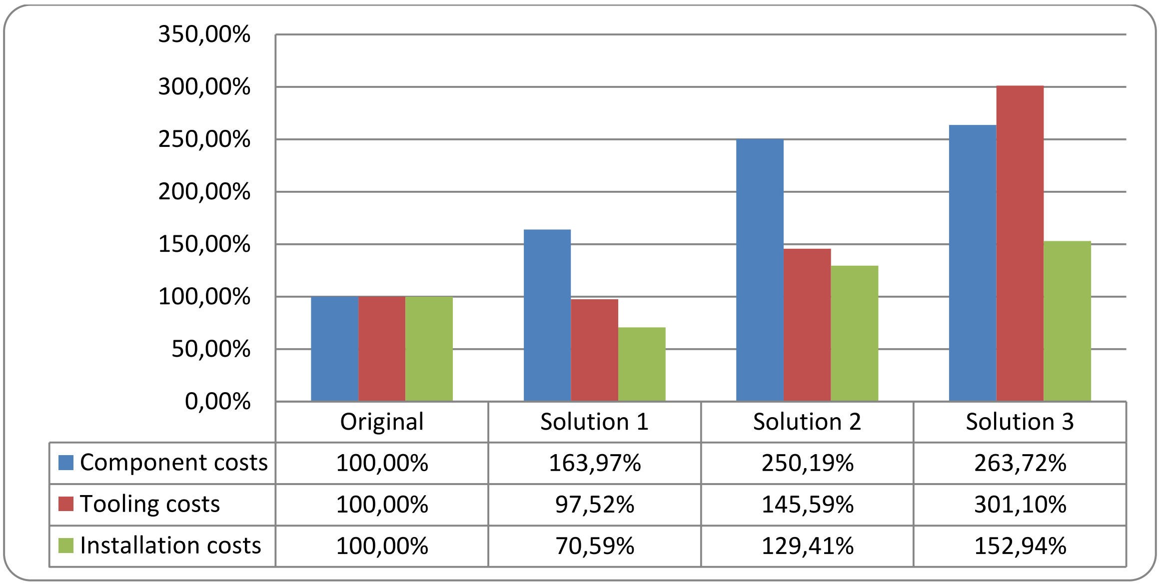


	Original	Solution 1	Solution 2	Solution 3
Tooling cost for manufacturing	100,00%	90,48%	66,67%	38,10%
Labour cost for installation	100,00%	125,00%	75,00%	75,00%

Figure 28. Costs for tooling and installation

Value comparison and judgment

Value between each design is based on the given grades and quotation costs. Value that each function provides to customer is compared in three different cost categories. Values of each category are presented in figure 29. It is clear that solution 3 is providing the best overall value to the customer. According to results solution 3 is the most valuable design and it is chosen to be developed in next steps.



	Original	Solution 1	Solution 2	Solution 3
Component costs	100,00%	163,97%	250,19%	263,72%
Tooling costs	100,00%	97,52%	145,59%	301,10%
Installation costs	100,00%	70,59%	129,41%	152,94%

Figure 29. Value comparison

3.4 Design validation

According to the value comparison solution 3 is chosen to be further developed. The design is validated with test prototype. The prototype is modified during the tests as an iterative process to fulfill needed requirements. Prototype is tested against three load cases required in EN 115-1. Design is studied from installation and manufacturing point of view. Functionality test is done by studying balustrade vibrations.

For the test three different bracket types are designed and purchased from KONE suppliers. Two different designs for roller tracks are also designed and purchased. Purchased samples and prototype designs are introduced in appendix 6. Prototype numbers and used components for each test are presented in table 7. Each tested structure has screw fixing to connect roller tracks to carry the passenger load. This connection is calculated and results are presented in appendix 7. All three bracket types are tested for rated load and studied from installation and manufacturing view of point. Based on the results two of the most suitable ones are tested for balustrade strength and the most suitable is tested for balustrade vibration.

Table 7: Prototype numbers, used brackets and roller track designs

Test	Prototype	Bracket type			Roller track bushing	
5.2.5 Supporting structure test	R2.0	1	2	3	Welded	Inserted
5.5.2.3 Balustrade strength test	R2.0 R2.1	1		3	Welded	Inserted
5.5.2.4 Balustrade strength test	R2.1 R2.4			3	Welded	
Vibration test	R2.1 R2.4			3	Welded	

3.4.1 Supporting structure test results

All three bracket types are tested against the rated load. Tested prototype is according to R2.0 design. There are two load cases for each bracket type. This way maximum deflection can be measured from two different locations. Deflections are measured from middle of the cross beam and from the roller tracks between two brackets. Test plan and system for the supporting structure test is presented in appendix 10.

Maximum allowable deflection depends on the distance between the support points. Maximum deflection for cross beam is 2.21 mm and permanent deformations are not allowed. Maximum deflection for roller tracks is 1.33 mm. The displacement is measured from top of upper roller track on left and right side. Displacement of lower roller track is measured from right side. All tested bracket types passed both tests. Bracket type 3 has the biggest deflections in both tests. Results for cross beam deflections are presented in table 8 and roller track deflections in table 9.

Table 8: Cross beam displacement under rated load, R2.0

Bracket type	Deflection under rated load		Deflection after load released	
	Test 1	Test 2	Test 1	Test 2
1	1.70 mm	1.39 mm	0.18 mm	0.03 mm
2	1.86 mm	1.47 mm	0.21 mm	0.05 mm
3	1.89 mm	1.81 mm	0.07 mm	0.01 mm

Table 9: Roller track displacements under rated load, R2.0

Bracket type	Position of the dial indicator	Deflection under rated load	Deflection after load released
1	Upper roller track - left	1.00 mm	0.08 mm
	Upper roller track - right	0.74 mm	0.04 mm
	Lower roller track - right	0.58 mm	0.02 mm
2	Upper roller track - left	0.71 mm	0.19 mm
	Upper roller track - right	0.78 mm	0.14 mm
	Lower roller track - right	0.46 mm	0.08 mm
3	Upper roller track - left	1.07 mm	0.11 mm
	Upper roller track - right	1.03 mm	0.12 mm
	Lower roller track - right	0.56 mm	0.06 mm

3.4.2 Balustrade strength test

Balustrade strength test is done to validate that the design is in compliance with clause 5.5.2.3 in EN 115-1. Test according to the clause 5.5.2.4 is done to have comparable deflection values with conventional KONE units. The claim in clause 5.5.2.4 is not relevant for glass balustrade. Based on the previous installation and manufacturing study the balustrade strength test is done by using bracket types 1 and 3. Test according to clause 5.5.2.3 is done with prototypes R2.0 and R2.1. Test according to clause 5.5.2.4 is done with prototypes R2.1 and R2.4 and by using only bracket type 3 and roller tracks with welded bushings.

Balustrade strength test according to clause 5.5.2.3 - Prototype R2.0

Test plan and system for R2.0 are presented in appendix 11. For test according to the clause 5.5.2.3, the balustrade did not broke or damage during and after the test. The biggest measured deflection for the bracket type 1 is 31.65 mm. This is value 114 % bigger compared to the original design. Used roller tracks in the test have inserted bushings. the biggest measured deflection for the bracket type 3 is 27.47 mm. This is 85 % bigger compared to the original design. Used roller tracks in this test have welded bushings. Measured deflection values are not acceptable as the difference to the original is considered to be too great. Detail results for the test are presented in appendix 11.

Balustrade strength test according to clause 5.5.2.3 - Prototype R2.1

Balustrade strength tests according to the clause 5.5.2.3 in EN 115-1 standard is repeated to prototype R2.1. Prototype R2.1 is modified to more rigid so that deflection of the balustrade would be smaller. The test is done only for the bracket type 3 and used roller tracks have welded bushings. Detailed test system and plan is presented in appendix 12. For test according to the clause 5.5.2.3 deflections were measured from eight different positions with dial indicators. Positions of the dial indicators and direction of positive coordinate axels are shown in figure 30.

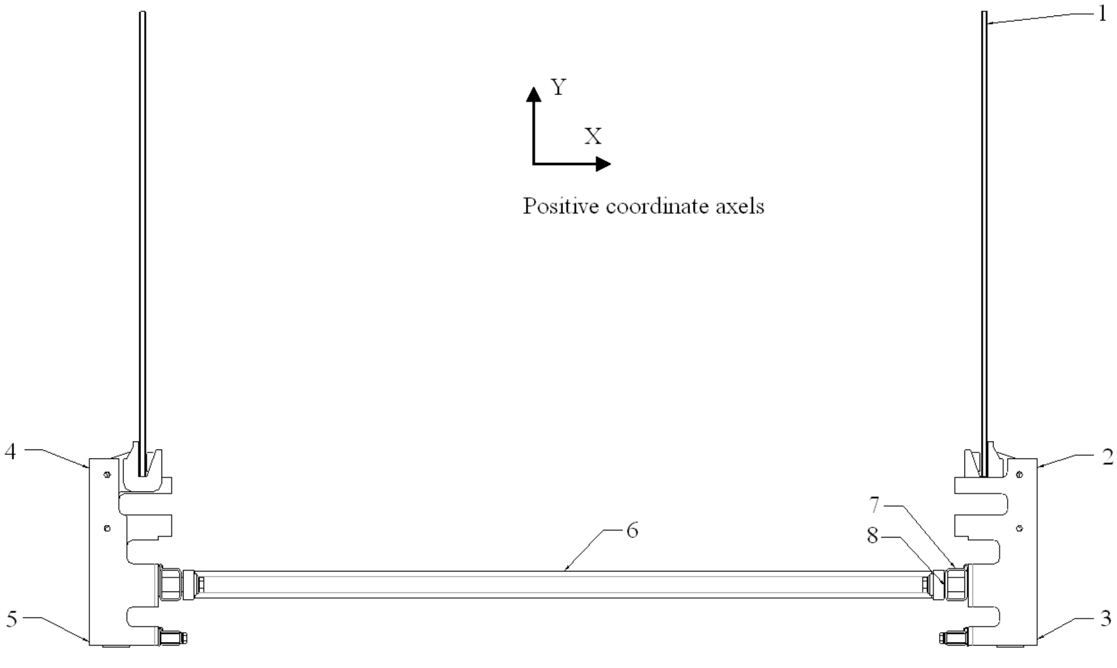


Figure 30. Position of dial indicators in balustrade strength test according to clause 5.5.2.3

Test according to the clause 5.5.2.3 was repeated twice and measured deflections are presented in table 10 and table 11. The glass panel was not broke or damaged during and after the test. The highest measured deflection is 48 % compared to original design.

Table 10: 1st balustrade strength test results, bracket type 3 - R2.1

Pos.	Deflection	Deflection after 10 min	Deflection after load released	Deflection after 10 min load released
Load	600 N Lateral 730 N Vertical	600 N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	18.96 mm	18.86 mm	0.31 mm	0.28 mm
2	0.96 mm	0.96 mm	0.04 mm	0.04 mm
3	-0.02 mm	-0.01 mm	-0.01 mm	-0.01 mm
4	0.50 mm	0.41 mm	0.03 mm	0.03 mm
5	0.08 mm	0.08 mm	0.00 mm	0.00 mm
6	0.10 mm	0.10 mm	0.01 mm	0.01 mm
7	0.16 mm	0.16 mm	0.01 mm	0.01 mm
8	0.18 mm	0.19 mm	0.02 mm	0.02 mm

Table 11: 2nd balustrade strength test results, bracket type 3 - R2.1

Pos.	Deflection	Deflection after 10 min	Deflection after load released	Deflection after 10 min load released
Load	600 N Lateral 730 N Vertical	600 N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	21.91 mm	21.87 mm	0.00 mm	0.00 mm
2	1.10 mm	1.10 mm	0.02 mm	0.03 mm
3	-0.02 mm	-0.02 mm	0.00 mm	0.00 mm
4	0.59 mm	0.59 mm	0.01 mm	0.00 mm
5	0.09 mm	0.09 mm	0.01 mm	0.00 mm
6	0.13 mm	0.13 mm	0.00 mm	0.00 mm
7	0.20 mm	0.20 mm	0.00 mm	0.01 mm
8	0.23 mm	0.23 mm	0.01 mm	0.00 mm

Balustrade strength test according to clause 5.5.2.4 – Prototypes R2.1 and R2.4

Test according to the clause 5.5.2.4 is executed for prototypes R2.1 and R2.4. Used tests are done with bracket type 3 and roller tracks with welded bushings. Deflections were measured from four different positions on the glass panel. Positions are presented in figure 31. Results from test according to the clause 5.5.2.4 are presented in table 12and table 13.

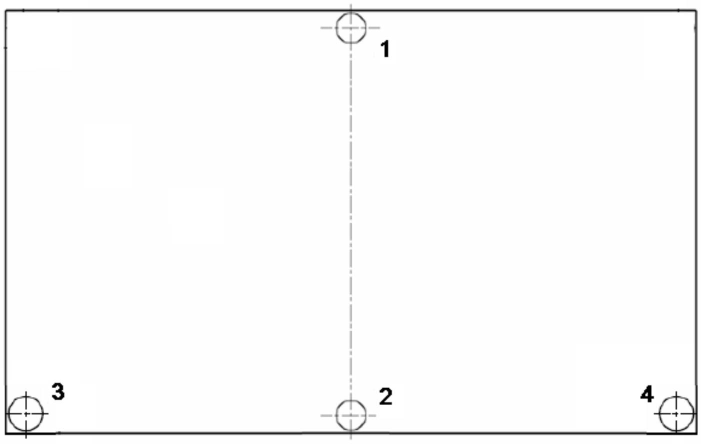


Figure 31. Position of dial indicators in balustrade strength test according to clause 5.5.2.4

Balustrade strength test according to clause 5.5.2.4 for prototype R2.1 there were no permanent deformations. The biggest deflection is 17.66 mm and it is 73 % bigger compared to the original design.

Table 12: Prototype R2.1 - Test results according to clause 5.5.2.4

Position	Deflection under 500 N		Deformation after load released	
	Left	Right	Left	Right
1	17.66 mm	-	0.50 mm	-
2	2.11 mm	-	0.02 mm	-
3	0.70 mm	-	-0.01 mm	-
4	0.55 mm	-	-.0.01 mm	-

Balustrade strength test according to clause 5.5.2.4 for prototype R2.4 there were no permanent deformations. The biggest deflection is 13.3 mm and it 33 % bigger compared to the original design.

Table 13: Prototype R2.4 - Test results according to clause 5.5.2.4

Position	Deflection under 500 N		Deformation after load released	
	Left	Right	Left	Right
1	13.3 mm	-	0.10 mm	-
2	1.69 mm	-	0.00 mm	-
3	0.41 mm	-	0.03 mm	-
4	0.42 mm	-	0.02 mm	-

3.4.3 Balustrade vibration test for design validation

Balustrade vibration test is done to ensure that vibrations in InnoTrack™ will not excite the balustrade to oscillate. Considered causes that might excite the balustrade to oscillate are pedestrian excitation, vibrations from reverser system and vibrations from pallets running between support points. Response frequencies of the balustrade system are measured with EVA 625 acceleration meter. Balustrade vibration test is done to prototype designs R2.1 and R2.4.

Based on the studies presented in appendix 13 the acceptable natural frequency of the tested balustrade system is 7 Hz or more in lateral direction if excitation is on the pallet. When excitation comes from the reverser system the acceptable limit is 4 Hz or more. These cases are in limits of a normal use of a moving walk. Vibrations caused by misuse are not considered in this study. (HiVoSS (Human induced Vibrations of Steel Structures), 2008; Newland, 2003)

Balustrade vibration test - Prototype R2.1

Detailed test is presented in appendix 13. According to the test for R2.1 the balustrade system has the first response frequency at 5.0 Hz and the second at 5.7 Hz. Both of these modes can be excited by jumping on top of the pallet and by striking the balustrades glass. Both modes are less than 7 Hz and therefore pedestrian excitation might excite the balustrade to oscillate. Prototype design R2.1 is not suitable to for moving walk.

Balustrade vibration test - Prototype R2.4

Detailed test plan for the second vibration test is presented in appendix 14. Presented results are all vibrations in lateral direction, normal to the balustrade glass panel. Frequency is presented in frequency spectrum. Respect to the Z-axis which is normal to the balustrade glass panel.

Vibrations are measured in three different tests. In the first test the accelerometer is attached to the right side balustrade. Balustrade is excited by striking the balustrade glass. In the second test the sensor is also attached to the right side balustrade but the system is excited by jumping on the pallet. In the third test the sensor is attached to left hand side and balustrade is excited by striking the glass panel. Each test is repeated three times to ensure valid data. The first frequency spectrums from each test are presented in figure 32.

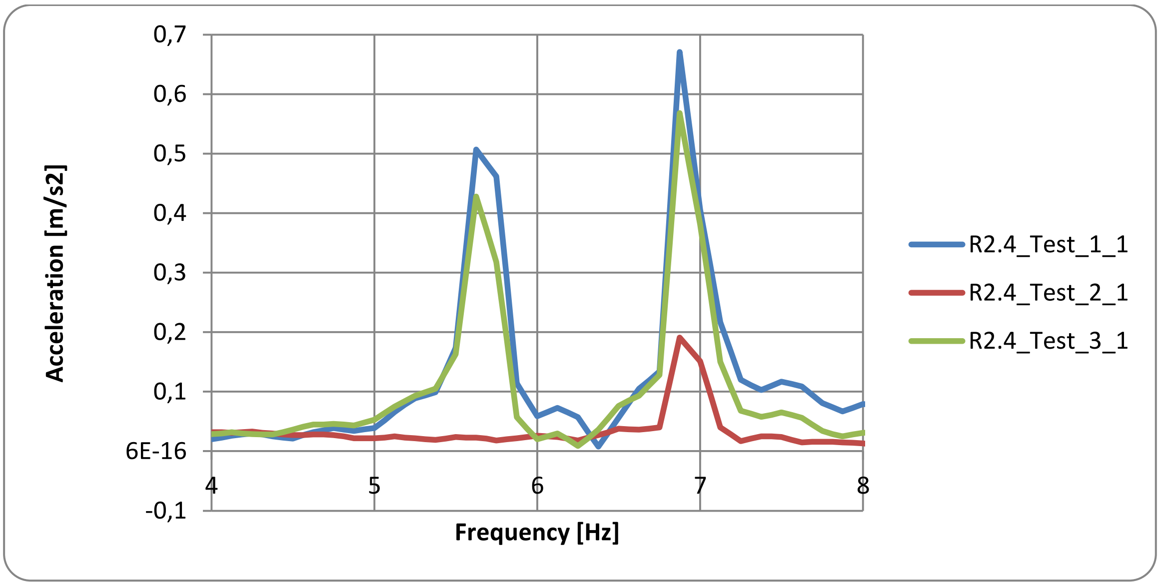


Figure 32. Test 1, 2 and 3, Frequency spectrums from 4 Hz to 8 Hz

From figure 32 it can be seen that when balustrade is excited by striking the balustrade there are response frequencies at 5.6 Hz and 6.9 Hz. When the system is excited by jumping on the pallet the first response frequency is at 6.9 Hz. The second test was repeated three times and the measured frequency spectrums from this test are presented in figure 33.

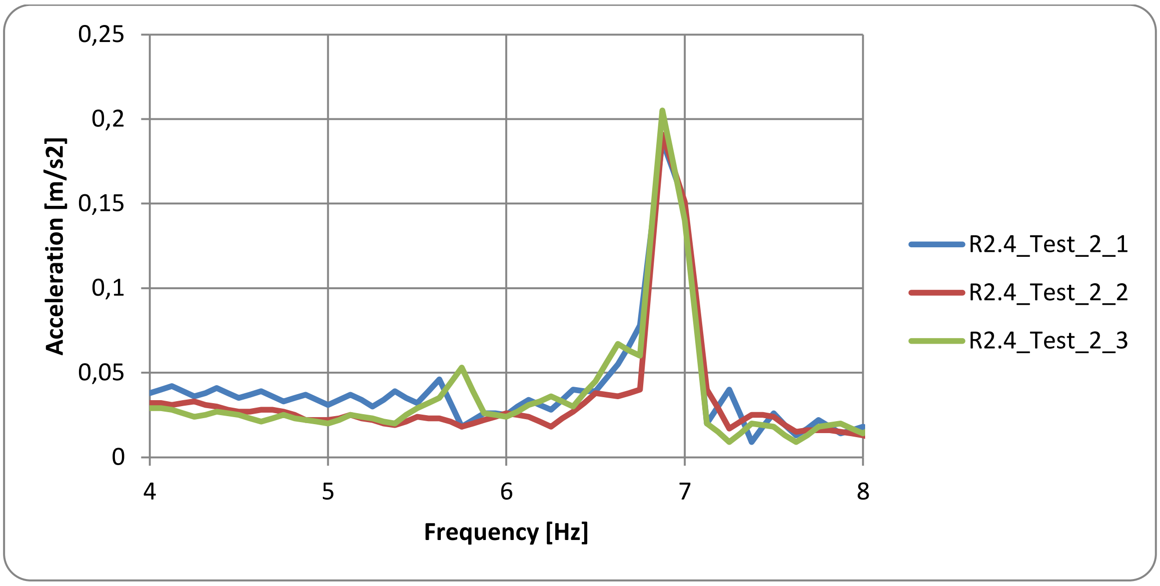


Figure 33. Test 2, Frequency spectrums from 4 Hz to 8 Hz,

There are clear response frequency peaks at 6.9 Hz and no indications that 5.6 Hz mode of the balustrade could be excited from the pallet. Higher modes are above 10 Hz and can be ignored. Based on the information in literature related to pedestrian excitation it can be said that pedestrian excitation is will not excite 6.9 Hz mode. Excitations from reverser system and pallets running between the support points will not excite the balustrade to oscillate.

3.5 Follow up development and final design

Tested prototype is developed further to give the utmost value to customer. Development is done according to the gathered information from prototype tests. Supporting structure for final design has angle profile roller tracks instead of hollow profile and therefore the supporting structure is calculated with finite element method. Final design for supporting structure is presented in figure 34.

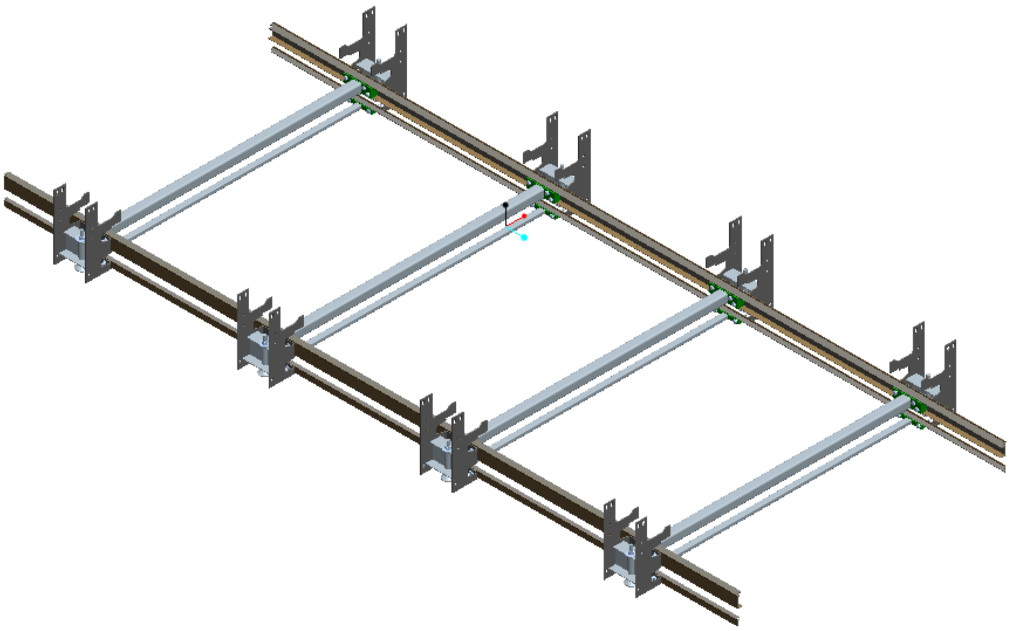


Figure 34. Supporting structure – R2.5

The load carrying structure is calculated with finite element method software ANSYS. There are two different calculation models and they are presented in appendix 15. The self-supporting bracket in the calculation model is simplified and contains only the base of the bracket. Load case for these calculation models is same as in previous calculation for supporting structure. According to the results the structure can with stand the load and the deflections are less than acceptable maximum. Deflection results from this calculation are presented in figure 35 and detail deflection values in table 14. Calculated deflections are less than acceptable maximum. Von Mises stress distribution is presented in figure 36. The highest stress is 314.5 MPa. Stress peak can be ignored as a singularity point. This assumption can be made as the peak occurs inside of two elements. The principal stress in the peak is compression. In reality these components are not boned and therefore it can be said that the stresses in the structure are generally below 180 MPa.

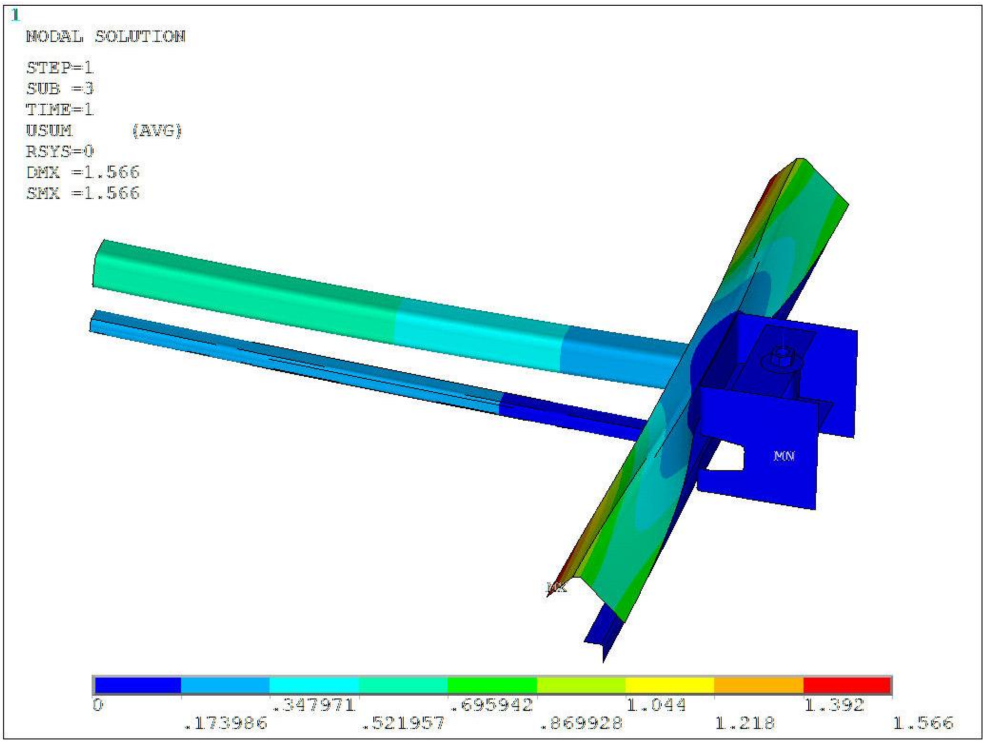


Figure 35. The vector sum deformation distribution

Table 14: Deflection values of the calculation model 1

Node	Deflection Y-axis	Component	Acceptable deflection
Max	-1.566 mm	Upper roller track	-
4238	-0.64898 mm	Upper cross beam	2.21 mm
9202	-0.62287 mm	Upper roller track	1.33 mm
9362	-0.62477 mm	Upper roller track	1.33 mm

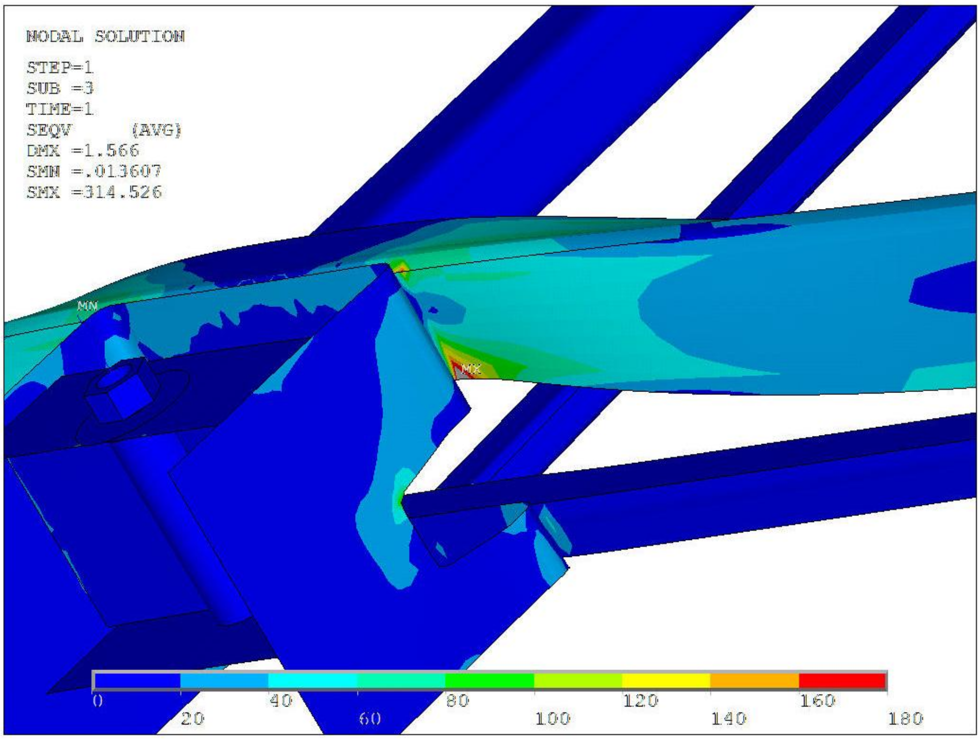


Figure 36. Von Mises stress distribution

3.5.1 Value of the final solution – R2.5

Component costs for R2.5

Costs for design R2.5 are compared to the original design and cost models are presented in figure 37. Quotation costs in figure 37 are related to yearly volume. There are three different volume scenarios presented. Each unit is considered to be 48 meters long. In the first scenario volume is one sold unit per year. The second scenario is five units per year and the third ten units per year. According to the quotation costs components for middle section module based on R2.5 design are -67.60 % compared to original costs of InnoTrack^{TM} middle section. The difference between each volume scenario is relatively small. Difference between one and five sold units is -1.44 %. The costs for 10 sold units per year are -3.29 % compared to volume of one sold unit per year.

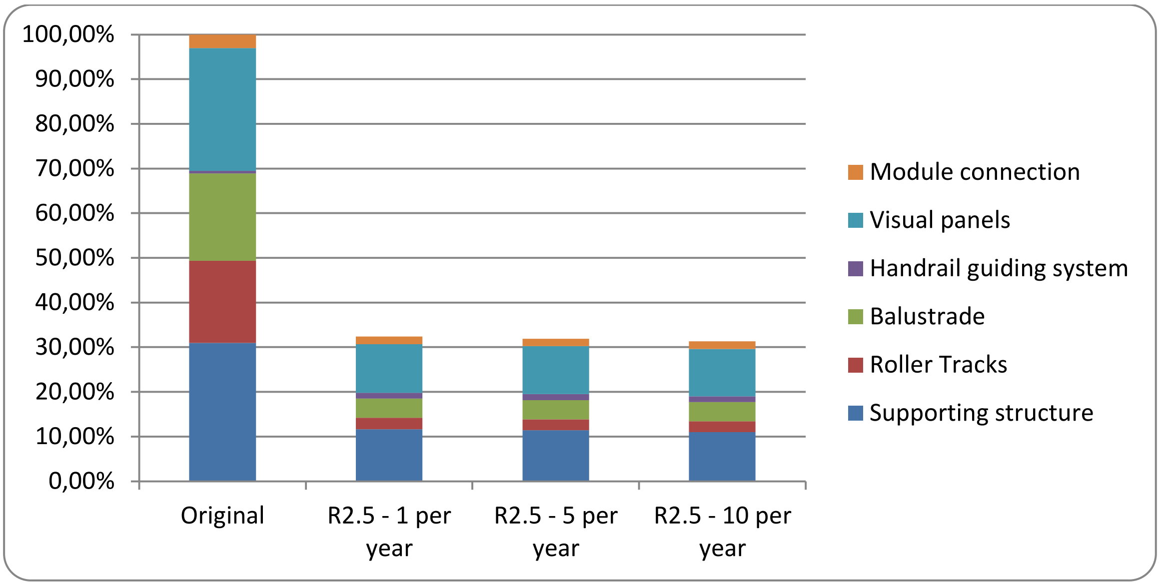


Figure 37. Cost models for original and R2.5 design

Manufacturing tool and installation costs for R2.5

Only required tool for manufacturing R2.5 design is a mould for plastic support roller. This roller is used in original design but due to the reason that InnoTrack^{TM} is manufactured in Europe, KONE suppliers in China can't manufacture the roller without a mould. Manufacturing tool costs for R2.5 are -91.4 % less compared to original design. Other components that would require moulds such as glass holder and handrail guiding profile are same as used in conventional units and are available in China. Installation time of R2.5 middle section module is considered to be the same as for the original solution.

Satisfaction of needs

R2.5 design is studied and concluded that it provides better satisfaction to customers' needs compared to first self-supporting bracket system design. Four out of six function groups are providing higher satisfaction than R2.0 design. Development is due to the design changes in these groups. Function group grades for R2.5 are presented and compared to the other design in table 15.

Table 15: Satisfaction of needs

Function group	Original	R2.0	R2.5
Supporting structure	3.0	9,0	10.0
Roller Tracks	6.0	9,0	10.0
Balustrade	6.0	4,0	5.0
Handrail guiding system	8.0	3,0	3.0
Visual panels	4.0	7,0	8.0
Module connection	7.0	7,0	7.0
Average grade	5,67	6.5	7.17

Value for the customer

Value between R2.5 and original design is based on the given grades and quotation costs for one sold unit per year. Customer value is compared in three different cost categories like in creativity step. Value for each category is presented in figure 38.

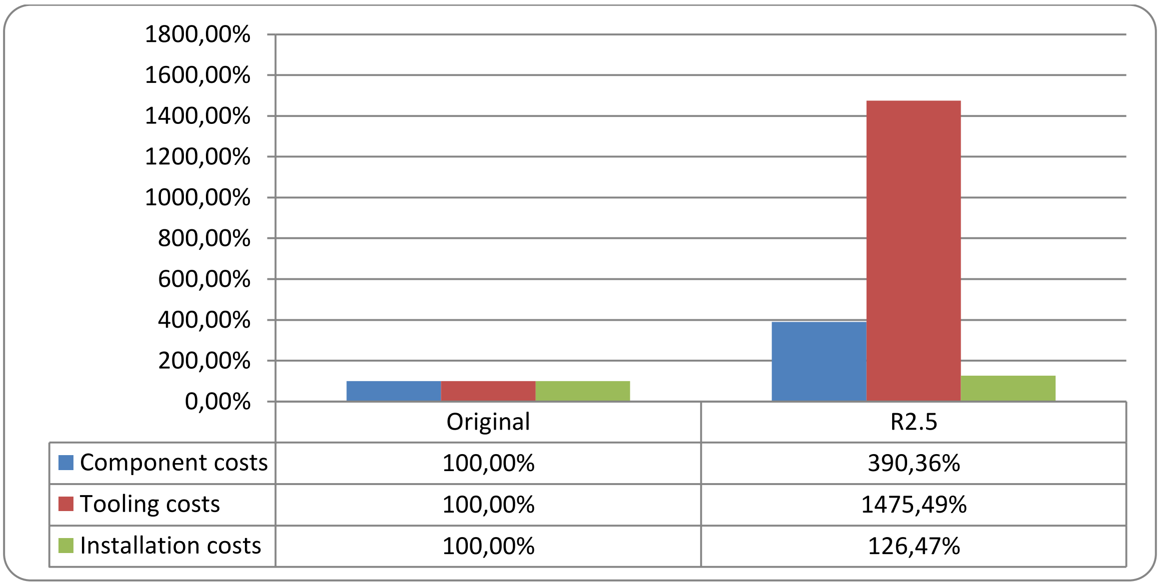


Figure 38. Value comparison for R2.5

4 DESIGN EVALUATION

Development of the middle section module is done according to value analysis. InnoTrack^{TM} is a released product which has not redeemed business expectations. Value analysis is chosen to be used to re-engineer the design. This is due to the reason that the unit is not providing enough satisfaction to the customer with current costs.

According to previous studies done at KONE, there are several actions that could be executed to reduce the costs of the original design. Actions listed by Markus Heinrichs in diploma thesis “Total cost analysis of an autowalk supply chain and resulting reductions” are: produce components in a low cost country, harmonize components between conventional units and improve the supply chain. Internal KONE analysis for InnoTrack^{TM} shows that by selling five units per year the cost of a middle section module would be reduced by -36 % and with volume of 30 units per year the reduction would be -43 %. KONE could set the unit price lower to gain these mentioned yearly volumes. However KONE has a clear strategy to sell products and services with profit and therefore the unit cost needs to be always profitable. (Heinrichs, 2008; KONE Corporation c, 2011)

Redesigning according to the value analysis opens more opportunities for the device. It is known that the original design holds the whole design history and the extruded aluminum truss profile is the bottle neck for re-engineering of other modules. This is the reason why value analysis in this thesis is done to the middle section module.

4.1 Gathered information

Manufacturing drawings and 3D models for the original design are available in KONE product data system, PDM. Previous tests, calculations and design modifications done for InnoTrack^{TM} are well documented. Most of the original designers have left KONE and information regarding to the original design is mostly gathered from documents in KONE PDM system and by discussing with KONE employees who have been involved in InnoTrack^{TM} project after the product was released. InnoTrack^{TM} is fairly new product and it is well documented and archived. Due to this reason it can be said that the author has sufficient amount of information available for the value analysis.

According to the presented results of the value analysis there are seven listed needs for customers of InnoTrack^{TM}. These needs are listed based on the understanding of the markets. Decisions are made by author and supported by employees in KONE technology organization. The results are not based on customer inquiries and due to this reason the needed functions and function groups are assumptions. It can be said that needs for flat autowalk are well understood in KONE Technology organization. Taking into account the scope of this thesis, internal knowledge provides sufficient amount of information for the needs.

Need to fulfill requirements in EN 115-1 has 50 % weighted value and the reason for this is safety. EN 115-1 standard is created to ensure that sold units are operating safely and more importantly that units are safe to use and maintain. Function groups listed in chapter 3.2 are related to the requirements in the standard. Additional tasks in the function groups are to please aesthetic needs. Customers for KONE are more and more interested about the aesthetic features in escalators and moving walks.

4.2 Created ideas and design verification

Created ideas in creativity step are created by using the function groups. Each solution fills the tasks of the function group in different way. Solutions are based in different existing ways to build moving walk units. Each created design is analyzed either by finite element method calculations or comparing to existing designs.

The first idea of reduced aluminum truss profile is based on the original design. The advantage is to make manufacturing of this profile easier. However this design still has all the same problems as the original unit. Therefore the performance of the design is almost the same as in the original design. According to component cost quotations the created idea is cheaper compared to the original. This difference is mainly due to the reason that quotation costs for the components are from Chinese suppliers and compared to the original costs which are from European suppliers.

Second solution roll formed steel combitrack system is based on the patent US 8,042,675 B2 self-supporting guiding system for moving walk. This idea provides higher satisfaction for customers' needs with much lower price than the original design. The created design has still issues from manufacturing point of view. Roll formed profile is big and requires strict tolerances. The balance between strict tolerance and low manufacturing cost is always challenging to achieve. The biggest issue for the created solution is the similarity with the patent which belongs to KONE rival company. (Gonzalez, 2011)

The third solution self-supporting bracket system for moving walk is based on the current way to build escalators and moving walks. In conventional units multipurpose brackets are used to support pallet band and skirting profiles. In this created solution the bracket is used to fix all functions. The idea is provides better satisfaction to customers' needs than the original. Main reason for this is that the structure is not integrated like the original design. The integrated design in original solution is the main reason why the costs are high. Simple components manufactured in simple way ensure low purchasing costs and also possibility to modify the structure in future.

Calculations in creativity step were done with PRO/Engineer Mechanica tool. The Mechanica tool is based on finite element method but the elements that software uses are not as accurate as in other commercial finite element method software's. The calculation models in creativity step uses solid elements and the mesh is done by using auto mesh tool. Therefore the calculations are only indicative and cannot be used to verify the design. However the calculations are to provide understanding of the feasibility of each created idea. Based on these calculations it can be seen if the designed structure is suitable for further development. The use of Mechanica tool is justified as the calculations can be done in short time and the structure is to be validated with prototype tests. Calculation models are analyzed in chapter 4.3.2.

4.2.1 Resources and satisfaction of needs

Satisfaction of needs is based on listed advantages and disadvantages of each created solution. These advantages and disadvantages are based on author's knowledge and understanding of the flat moving walk product. Therefore these grades are not absolute values. However amount of disadvantages respect to advantages corresponds to the given grade. Taking into account the scope of this thesis and the stage of the created designs the used method is adequate. Comparison between solutions is presented in appendix 5.

In this thesis the overall costs for the created solutions are not calculated. Overall costs can't be estimated as there are too many unknown variables. Results would be rough estimations and inaccurate. InnoTrack^{TM} is fairly new product and there is no overall cost calculations available for the unit. Therefore the costs are limited to components, manufacturing tools and installation time. These are assumed to be the most critical factors to the overall costs. Costs for installation are compared in time. This is due to the reason that labor cost is depending highly on the country where the unit is installed. The consequence of the installation time can either be the biggest factor or irrelevant if the unit is installed in a country where labor costs are minimal.

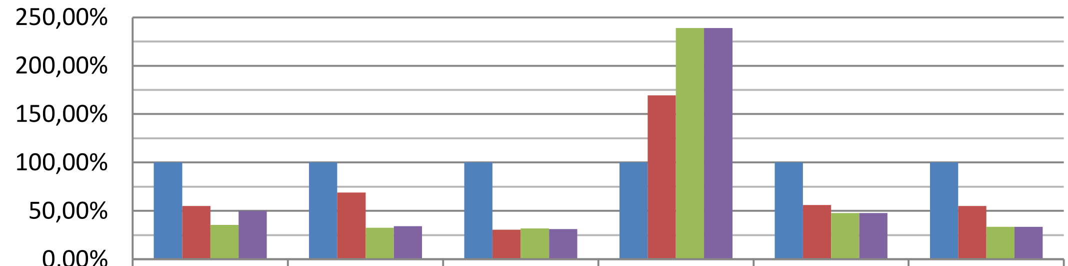
Calculated component costs for solutions created in creativity step are quotation prices that KONE suppliers have provided. Remaining costs are based on reference costs from components used in conventional solutions. For example: costs of the skirting, cladding inner and outer decking are based on costs of standard KONE escalator unit.

Chinese suppliers are usually interested on the component volume. Component purchasing costs are therefore depending greatly on the yearly volume. Higher the volumes are the lower the price of a single component is. Estimations for component volume are not used when negotiating quotation prices in creativity step. Some of the components in designed solution 1 are same as in original InnoTrack^{TM} middle section. The quotation costs for these components are from project to relocate InnoTrack^{TM} production to China. These costs are negotiated with supplier by KONE sourcing department. Other components are based on reference components.

The component costs for the solution 2 are the lowest. This solution uses roll formed steel profile and the costs for this profile are relatively low compared to the steel pipe profiles used in solution 3. According to the sourcing department the cost for this profile is only for reference. Without reasonable volume the cost for a roll formed profile can be assumed to be higher than the provided quotation cost. Roll forming is a manufacturing method that is usually profitable only with steady yearly volume. In the case of InnoTrack^{TM} there is no expected yearly volume. Only couple components in solution 3 require a mould. Therefore the quotation costs for solution 3 are actual purchasing costs for samples. Quotation costs for samples are usually more expensive than quotations for components related to volume.

However it is justified to use these sample costs to evaluate the costs as the designs are not detailed in creativity step.

Development of component costs between each function group can be seen from figure 39. Handrail guiding system is the only group where component costs are higher for created solutions. However this group holds only less than 1.50 % share of the costs in each solution. Besides the handrail guiding system costs reductions are divided evenly between function groups.



	Supporting structure	Roller Tracks	Balustrade	Handrail guiding system	Visual panels	Module connection
Original	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Solution 1	55,19%	68,92%	30,72%	169,50%	56,02%	54,98%
Solution 2	35,59%	32,50%	32,02%	239,00%	47,94%	33,60%
Solution 3	50,17%	34,33%	31,25%	239,00%	47,94%	33,60%

Figure 39. Cost comparison between function groups

Installation time for the original unit is not available. Only data related to installation time is estimation. Created solutions are compared to the original unit with this estimation. Solutions 2 and 3 are assumed to be -25 % compared to the original design. The installation costs for solution 1 are 25 % more than for original solution. These estimations for installation time are inaccurate. However the differences are based on the differences in designs. Solution 1 has higher installation time as there is more components than in original solution but still there is a need to glue and level the aluminum truss profiles respect to floor. Solutions 2 and 3 are considered to be faster to install as there is several functions in the designs that make installation easier. The biggest advantage compared to original is the possibility to adjust the foot respect to the floor.

Information about the tooling cost for the original solution is not available. This is due to reason that original extruding mould is paid by the supplier. To have a reference for the original model the mould price for original design is from Chinese supplier. Comparing the tooling costs it is clear that solution 3 does not require big investments on tooling unlike solutions 1 and 2. This is a great asset as there is no yearly volume.

Value

Judgment between different solutions was done based on the value that it gives to the customer. According to the results self-supporting bracket system provides the highest value to the customer. Main reason for this is that it uses simple components that do not require investments for tooling.

In this case where the volume for the product is low and is expected to stay low it is justified to have slightly more expensive components rather than high investments for tooling equipment. Depending on manufacturing process and volume the supplier might need to set up the mould to the machine which will effect to the component price if volumes are low or irregular. This consequence is not visual in costs presented in this thesis. Simple manufacturing method guarantees that the components can be manufactured globally and they are not depending on the location of the die cast or roll forming mould. This could mean savings from the logistic costs if components can be manufactured close to the site where the unit is sold. Components in solution 3 are simple to manufacture and the tooling costs for this solution are the lowest out of the three different ideas.

4.3 Evaluation of the development

Development of the chosen idea is done as an iterative process. Design is validated by executing tests in KONE escalator laboratory. During tests the problem areas are identified and structure is developed accordingly.

4.3.1 Test systems

Detailed analyze of each test system is presented in appendices 10 to 14. Each test is done by using prototype of the middle section module. During the tests the prototype was modified and all together three different prototype designs are used. The first prototype R2.0 is built according to the design in creativity step. For this prototype there are three different types of self-supporting brackets and two different designs for roller tracks. Different designs are used to compare the manufacturing accuracy of the components and also installability. Different designs for brackets and roller tracks are purchased to save time. The investment for the higher number of samples is justified as the delivery time for each prototype would have been one month. Three different tests are done to validate the design. Supporting structure test, balustrade strength test and vibration test.

Test system in each test is not fully corresponding complete unit. It is assumed that the prototype is working in similar way as it would in complete unit. This is due to the simplicity of the load cases and the fact that complete unit provides more constraints to the module. Tests are done by using prototype with nominal autowalk width of 1400 mm. InnoTrack^{TM} is also sold with width of 1000 mm and 1200 mm. Test prototype is chosen as the 1400 mm width is the highest and the step area is also the biggest which means the biggest load on supporting structure test. In case of balustrade strength test the load is always same. Width of the unit has positive effect to the balustrade strength as cross beams are shorter and the deflections are therefore shorter. This is based on beam theory. According to the same theory the structure is more rigid for balustrade vibrations.

4.3.2 Test results

Supporting structure test

According to the results from supporting structure test all tested variations for prototype R2.0 are compatible with the clause 5.2.5 in EN 115-1. From the displacement results it can be seen that the biggest displacement for the supporting structure is always in the middle of the cross beam. Cross beam displacement tests are executed two times and variance between results is considerable but not significant. When comparing cross beam displacements between the bracket types, bracket type 3 has the biggest displacement of 1.89 mm. The bracket type 1 has the lowest displacement with value of 1.37 mm. However when the load had been released the smallest recorded deformation was recorded with bracket type 3. Bracket type 3 has the biggest displacements also in roller tracks. Upper roller tack displacement is 1.07 mm on the left side and 1.03 mm on the right side. Bracket type 2 has the smallest displacements on upper track 0.71 on left side and 0.78 on right side. Permanent displacements were record for every bracket type. However the readouts are relatively small and more likely to be caused from movement of the structure when load was applied.

When comparing the test result to the calculations done with PRO/E Mechanica tool it can be seen that in rated load case the structure works in similar way as the calculation model. The difference between the measured and calculated deflections is 43 % which is notable big difference. The measured deflections in the concept prototype are bigger than the calculated. The reason for this difference is coming from the calculation model which uses solid elements. Calculation model uses also mirror constraints to reduce the model size and calculation time. Used solid elements and inadequate mesh is assumed to be the biggest reason for the difference. Solid elements are not capable to define the properties of a sheet metal component.

The clause 5.2.5 in EN 115-1 states that the rated load is distributed equally on the supporting structure. In the tests for the prototypes the load was applied on the upper roller tracks. The load is not applied in accurate way as the position of the load varies between each test. This causes variation between test results. Target for the test was to validate the design to meet requirements in EN 115-1. Used load in tests was bigger than the required load and based on this it can be said that the results are valid

Supporting structure for the original design is calculated in KONE document LAB-51.04.005. Calculation results and measured results from the tests can’t be compared directly. The span between support points is different and therefore maximum allowed deflection is also different. The results are compared in percentage from allowed maximum. In the original design the deflection is 9.67 mm and maximum allowable deflection is 10.31 mm. The deflection is then 94 % of the maximum. In tested prototype with bracket type 3 the biggest deflection was 1.89 mm and maximum is 2.21 mm. The deflection is therefore 85 % from the maximum. According to this comparison the prototype can carry more load than the original design.

Installation study

During the rated load test the structure was installed number of times and different bracket types were analyzed from installation and manufacturing view of point. It can be seen from the purchased patch that the supplier has ignored most of the tolerances marked in manufacturing drawings. Bracket type 1 has 4 independent walls for the fixing holes. These walls are not parallel against each other and therefore the distances between fixing holes are varying between brackets. Welded screw bars in bracket type 2 are not meeting the tolerance requirements. In some of the samples screw bars are misaligned so that bracket needs to be forced through the roller track holes. Bracket type 3 is bended two times and fixing holes for roller tracks are in same wall. This means that the distance accuracy between the holes is better than in solution 1. The tolerances on the fixing surface are depended on the laser cut machine not the bending process. This design is more accurate compared to other two solutions.

Purchased samples for roller track profiles are not suitable to be used in moving walk. Running surface of these samples is not smooth enough. Profiles are not straight enough which will cause problems for installation and also for the unit’s functionality. From manufacturing and installation point of view the design where the bushings are welded in to the track is better compared to the inserted one. The positioning of the welded bushings to be parallel to each other and perpendicular to the running surface is a challenge from manufacturing point of view.

Each bracket has adjustable foot but due to the design differences only bracket type 3 is easy to adjust. Fitter can access the bracket from both sides unlike for bracket types 1 and 2. Design for bracket types 2 and 3 allow fitter to use only one wrench when fixing roller tracks. This can be concluded to be a great asset for installation. Distance between upper and lower roller track needs to be adjusted by the fitter. This applies for all bracket types. The fixing holes and used screws are not aligning the roller tracks automatically. Lack of this function is increasing the installation time.

Conclusion for the study is that bracket type 3 is the most suitable to be used as a supporting bracket. The design is not in wanted level in terms of installability. Fixing of the supporting bracket, crossbeam and upper roller track needs to be developed so that components can be fixed without adjustment.

Balustrade load test

Bracket types 1 and 3 are tested for balustrade strength according to the clause 5.5.2.3 in EN 115-1. Tested prototypes for this clause are according to the R2.0 and R2.1 designs. Prototypes R2.1 and R2.4 are tested according to the clause 5.5.2.4 and these tests are done only with bracket type 3 and roller tracks with welded bushings. Each tested bracket type and prototype design is in compliance with the EN 115-1 standard.

The calculation model for balustrade load case is according to the R2.0 design. This calculation model cannot be directly compared to the tested prototype. As the prototype does not act symmetrically respect to the longitudinal centerline when balustrade load is applied. The calculation model uses symmetry constraints to reduce the calculation time. Based on the tests the used constraints in calculations are wrong.

When the balustrade load is applied the R2.0 prototype structure deflects on a certain manner. Principle for deflections is presented in figure 40. Balustrade in R2.0 prototype is also prone to wave a lot when it is pushed and pulled. The structure works as a system and when left hand side balustrade is pushed and pulled the right hand side balustrade waves along.

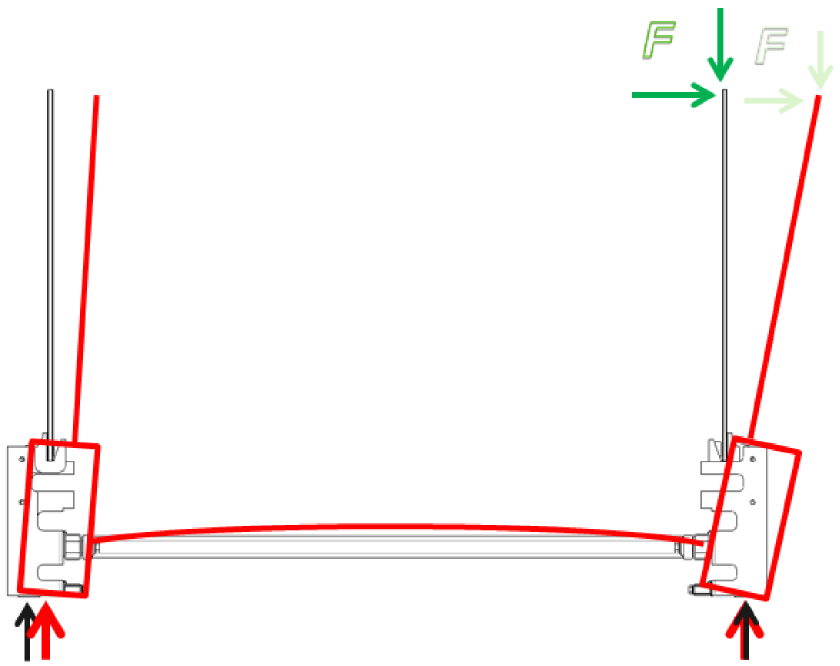


Figure 40. Deflection principles when balustrade load is applied

Measured deflection values for the R2.0 design are relatively high when balustrade load is applied. Both bracket types 1 and 3 have about the same deflection. Deflection values are compared to the original design of InnoTrack™ middle section. The biggest deflection of the balustrade in tested prototype R2.0 was 31.63 mm and in original design the same value is 14.82 mm. The difference between the tested units is 113 %. This is notable big difference and due to that reason the R2.0 prototype was modified. Due to the reason that the bracket type 3 is easier to manufacture and install rest of the tests were carried out by using bracket type 3.

According to the measured deflections on the prototype structures it is concluded that the spherical joints in self-supporting brackets are the pivot points. The figure 40 illustrates this movement in the system. Prototype R2.1 is modified accordingly and a lower cross beam is added to prevent the bracket to rotate. According to the repeated balustrade strength test the highest deflection of the prototype R2.1 is 48 % bigger compared to the original unit. From the detailed results in appendix 12 it can be seen that other measured deflections reduced 50 % or more after reinforcing the structure with lower cross beam. The lower cross beam did not prevent both balustrades to wave when another one is pushed and pulled.

The prototypes are tested against the load according to clause 5.5.2.4 because other KONE units have measured data on this load case but not for the load according to clause 5.5.2.3. Test according to clause 5.5.2.4 is done to prototypes R2.1 and R2.4 comparison between these prototypes and different KONE units can be seen in table 16

Table 16: Comparison between measured balustrade deflections

Unit	Autowalk	Autowalk	Autowalk	Autowalk / Ramp	Escalator
Type	InnoTrack™ Proto R2.1	InnoTrack™ Proto R2.4	InnoTrack™ prototype 5	AJV / RJV	MAP1 Prototype 2
Document	LAB-54.04.020		LAB-54.04.008	LAB-54.04.010	LAB-54.04.014
Design	Prototype	Prototype	Released	Released	Released
Balustrade height	1000 mm	1000 mm	1000 mm	1000 mm	1100 mm
Glass panel height	863 mm	863 mm	863 mm	795 mm	831 mm
Span between glass holders	1000 mm	790 mm / 210 mm	Continuous	950 mm	1200 mm
Load according to 5.5.2.3	Top max: 21.91 mm	-	Top max: 14.82 mm	-	-
Load according to 5.5.2.4	Top max: 17.66 mm	Top max: 13.30 mm	Top max: 10.21 mm	Top max: 18.26 mm	Top max: 14.27 mm
	Lower end: 0.70 mm	Lower end: 0.42 mm	Lower end: 0.29 mm	Lower end: 0.27 mm	Lower end: 0.30 mm

Maximum balustrade deflections in prototype R2.4 are smaller compared to R2.1 when load according to clause 5.5.2.4 is applied. Deflections are however still bigger compared to original design. Balustrade strength test according to clause 5.5.2.3 is not repeated for R2.4 prototype. Reduction for deflection between R2.1 and R2.4 is 25 % when load according to clause 5.5.2.4 is applied. Based on this the deflection of R2.4 balustrade is less than in original when balustrade load is applied according to 5.5.2.3.

Major difference between original design for InnoTrack^{TM} and self-supporting bracket system is that original design behaves symmetrically respect to the longitudinal centerline when balustrade load is applied. Original design is more rigid and movement of the left balustrade does not reflect highly to the right side.

According to test system analyses in appendices 11 and 12 the prototype is not fully representing complete unit. The balustrade of an escalator and moving walk works as a system. This means that the length of the unit effects to the strength. Due to the design the balustrade is more rigid when section is longer. This is due to the reason that the load is distributed to several support points. In the tested system the number of support points is limited. Tested prototype for the balustrade strength test is four meter long and there is only three glass panels which are all together 3 meters. Skirting and decking panels would also make the deflections smaller but the effect to the results is assumed to be less than 5 %.

Balustrade deflection values for R2.4 prototype are in same scale as in other KONE escalator and autowalk units. Due to the previously mentioned reason the balustrade is more rigid in complete unit and it can be concluded that balustrade deflections in prototype R2.4 are acceptable.

Vibration test

Test prototypes R2.1 and R2.4 were tested for balustrade vibration. Tests are done to find out the natural frequency of balustrade system in self-supporting bracket system for moving walk. Test is done to validate that the pedestrian excitation can't excite the balustrade to oscillate.

According to the literature for design of footbridges the acceptable limit is 4.6 Hz. However Newland, E David presents measured data about frequencies when one is jogging or running. According to these results the acceptable limit is 6.4 Hz. Due to the reason that end users for moving walks are often also running or jogging on the unit the acceptable criterion for excitation frequency on pallet is set to 7 Hz. Other considered excitations from pallet reverser and travelling pallets will not be exited if the response frequencies are above 4 Hz.

According to the results the balustrade system of the prototype R2.1 has response frequencies at 5.0 Hz and 5.7 Hz. Both of these modes can be excited by jumping on the pallet. These modes are below the acceptable criterion and therefore the prototype R2.1 is not suitable for use. Other considered excitations from pallet reverser and travelling pallets will not be excited as the first mode is above 4 Hz.

To fulfill the frequency requirement the first mode that can be excited from the pallet band needs to be 7 Hz or more. Balustrade of a short section can be considered to work as pendulum and fixing point is a torsion spring. To increase the oscillation frequency this spring should be stronger. From the previous comparison of the balustrade deflections in table 16 it can be seen that the lower edge of the balustrade is deflecting more than in other solutions. This means that the upright plate in the bracket is bending under the vertical load.

During the vibration test of the prototype R2.1 also original design of InnoTrack™ and conventional KONE escalator MAP2 where tested. The results from these tests are presented in appendix 13. Original InnoTrack™ has completely different fixing method for the balustrade glass and therefore also results are different. The first response frequency is 7.5 Hz when balustrade is excited by striking the glass. MAP2 escalator has first response frequency at 5.0 Hz. This is similar to prototype R2.1. The fixing of the glass holder in MAP2 escalator is however stronger compared to the prototype R2.1 of self-supporting bracket system. Tested escalator balustrade system is complete and according to the test results it also has different modes compared to the short section. In complete unit reciprocating motion of a single point causes longitudinal waves. It is likely that when using self-supporting brackets the balustrade system would behave in similar way in complete unit.

According to the results from prototype R2.1 and MAP2 escalator it is concluded that the 5 Hz frequency is characteristic for the balustrade system. This complies when the system uses aluminum die cast glass holder and glass panel thickness is 10 mm. Due to this reason it is not enough just to modify the fixing of the aluminum glass holder to be more rigid. The balustrade glass panel deflects under the load and together with the actual fixing area of the holder it has great influence to the frequency of the system. In original InnoTrack™

design the connection area is multiple times bigger than when using aluminum die cast glass holder.

Based on the presented conclusions the prototype R2.1 is modified by adding second glass holder to the bracket. In the prototype R2.4 each balustrade panel is fixed with two aluminum die cast glass holders. This modification will divide the load to both upright plates on the bracket and at the same time provides bigger area to fix the balustrade glass panel.

Vibration test is executed again and according to the results the balustrade system has the first response frequency at 5.6 Hz and the second in 6.9 Hz. The first measured response frequency is 6.9 Hz when jumping on the pallet. Based on these results it is concluded that the functionality of structure is validated.

4.4 Presentation of the final design

Last step of the value analysis process in this thesis is the presentation step. The details for the design are presented and analyzed in following chapters. New design is compared to original unit and also to the first prototype. Satisfaction of need is valued respect to costs.

4.4.1 Design details

Supporting structure – R2.5

The supporting structure of the final R2.5 design is basically same as presented in creativity step. Differences are that there is two cross beams linking each bracket pairs and also the structure of the brackets is slightly different. Cross section for the supporting components is presented in figure 41.

Roller tracks – R2.5

In the final design steel angle profiles are used as roller tracks. Both upper and lower roller track profiles are according to a Chinese GB standard. The guiding nose profiles are bended sheet metal components which are installed between the bracket and roller track. The upper nose profile works same time as a counter guide for the lower pallet rollers. Roller tracks are highlighted in figure 41.

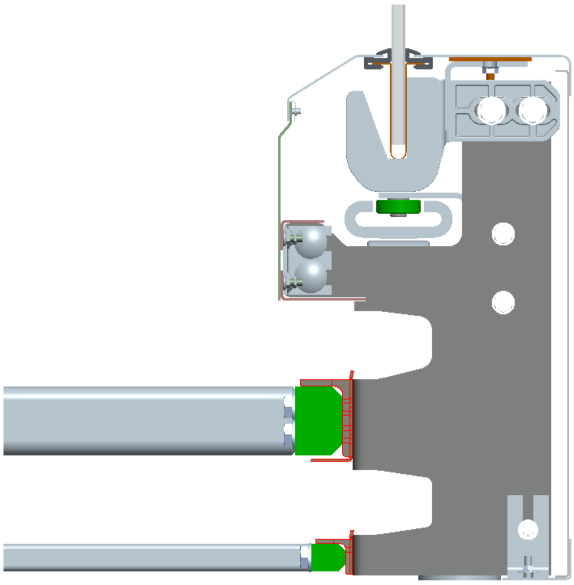


Figure 41. Cross section view of the right hand side self-supporting bracket

Tolerances for the structure are reviewed in appendix 9. In the final design spring pins are inserted to cross beam and placed through the bracket. These pins will align the left and right side brackets and both cross beams. Roller tracks are placed on top of the cross beam blocks which ensure the right height for roller tracks respect to each other.

Balustrade system – R2.5

Each balustrade glass panel has two fully attached die cast glass holders. This aluminum glass holder is a KONE design and used in conventional units. The glass holder is a cut model which means that part of the holder is machined. The self-supporting brackets are extended so that the glass holders will fit in. Therefore the whole unit is extended 23.5 mm per one side. The balustrade system is presented in figure 42.

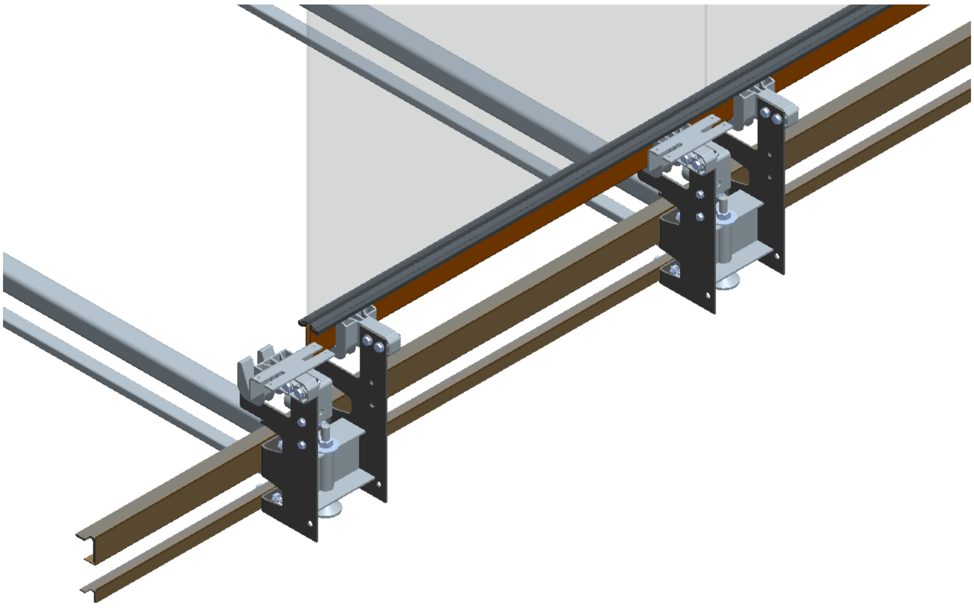


Figure 42. Balustrade system – R2.5

Handrail guiding system – R2.5

Handrail guiding system is presented in figure 43. The R2.5 design uses same support rollers and bearings as the original InnoTrack™ unit. Diameter of the plastic roller is 45 mm. To manufacture this plastic roller Chinese supplier needs a mould. The mould is available in Europe but not in China.

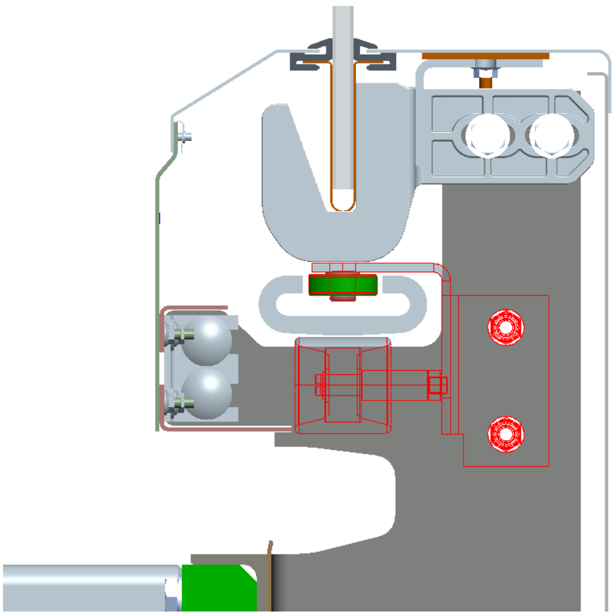


Figure 43. Handrail guiding system – R2.5

Visual components – R2.5

Skirting panel is fixed to the self-supporting brackets. There are two fixing points in each bracket. Design is presented in figure 44. Skirting plate is stainless steel and material thickness is 2 millimeters. Design is based on a previous KONE design which is calculated to fulfill the requirements in EN 115-1. Fixings for inner and outer deckings are copied from conventional units and they use same components. Cladding panel is inserted inside of the decking and an angle profile in lower end. Designs for deckings and cladding are presented in previous figure 41.

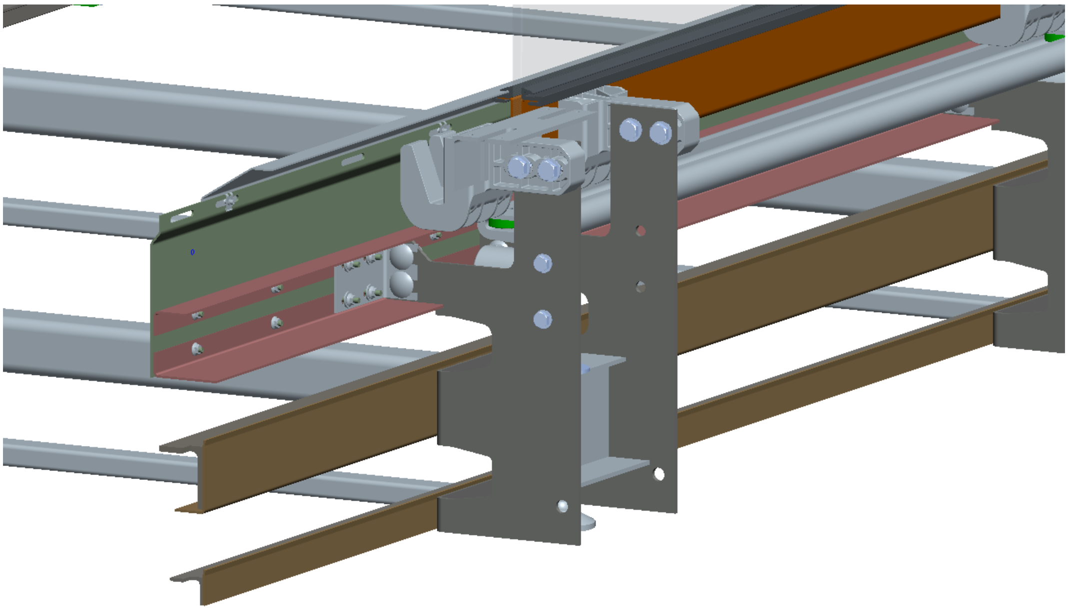


Figure 44. Skirting fixing – R2.5

Module connection – R2.5

Connection between two middle sections is presented in figure 45. The running track surface has a step in it to allow adjustable installation. The tracks are connected by using a machined steel block and after installation running surface is grinded. Skirting panels are connected with a simple angle profile connector. The connector is a bended sheet metal component which is fixed to skirting with screws. Split interfaces for different visual components are all clearly in different phase.

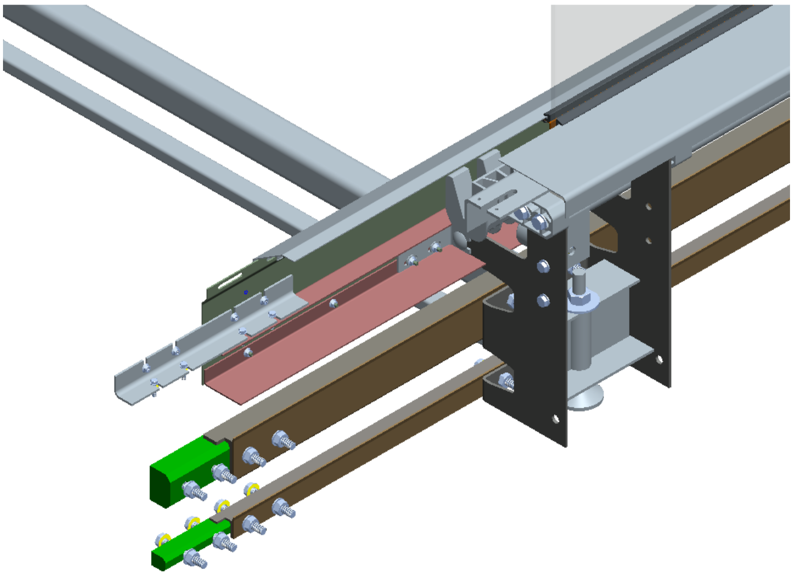


Figure 45. Connection between two middle sections – R2.5

Connection between middle section and drive head module is designed by using self-supporting bracket and machined steel blocks. Connection between middle section module and drive head module is presented in figure 46. Upper roller track of the middle section is connected to this machined steel block which is connected straight to the reverser system. The machined block is fixed to self-supporting bracket which enables additional support point. Lower roller track profile of the middle section is also fixed to a machined steel block. This lower steel block is fixed to buffer support plate in lower roller track of the drive head. Design for the buffer is presented in figure 46. Buffer material is rubber and it is supported by a steel plate. On top of the buffer there is a steel running track. The connecting steel block is fixed to the support plate of the buffer and the running track is overlapped and glued on top of the block to ensure fine ride comfort. Connections between steel blocks and roller tracks are adjustable in longitudinal direction.

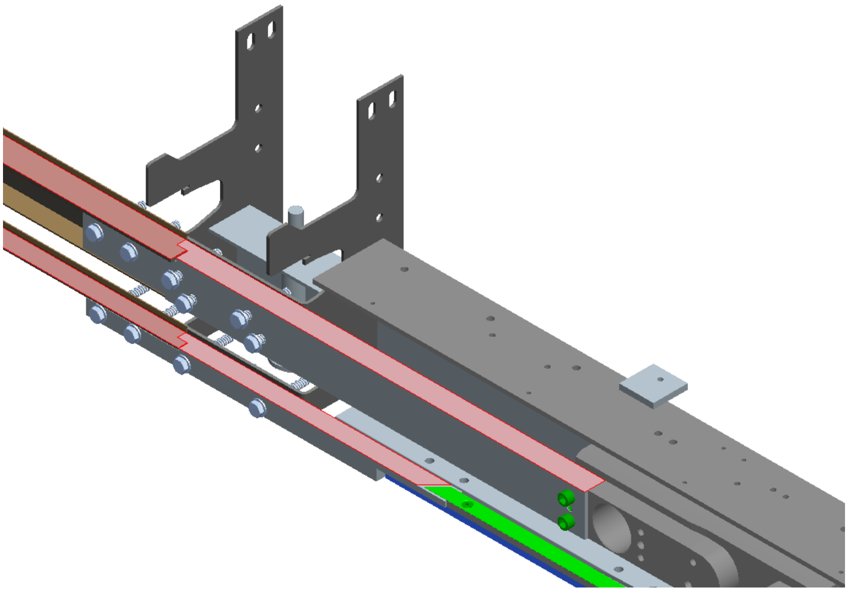


Figure 46. Connection between middle section module and drive head module – R2.5

Connection between middle section and tension head module is designed also by using self-supporting bracket and machined steel blocks. Connection between middle section module and tension head module is presented in figure 47. Upper roller track of the middle section is connected to this machined steel block. Together with another machined lamellar steel block these components are allowing floating structure for the reverser system. Lower roller track uses also machined steel block to enable connection. Lower roller track has also a running roller track plate like drive head. This running track plate is overlapped on top of the machined connection block on lower track to ensure smooth ride comfort. The plate is glued and fixed with screws.

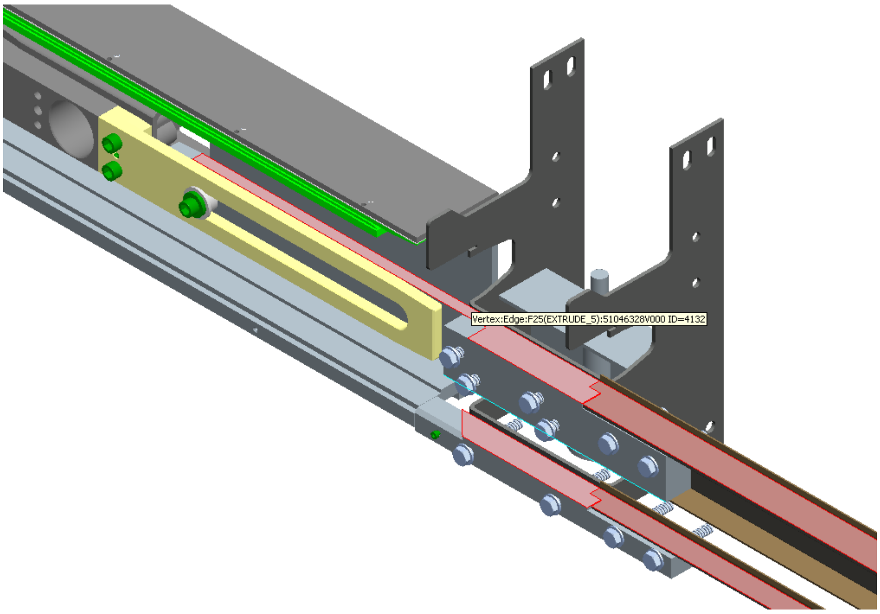


Figure 47. Connection between middle section module and tension head module – R2.5

4.4.2 Design analysis

Supporting structure and roller tracks

Prototype R2.4 is modified to be manufacturing and installation friendlier. According to the studies done to the prototypes, the roller tracks have high influence on the installation process. Hollow profile roller tracks are challenging to manufacture with strict tolerance requirements. R2.4 design uses upper and lower cross beams to connect left and right side brackets. The lower beams are needed to control the balustrade deflections. Lower cross beams are adding the rigidity of the supporting structure. This enables use of lighter roller track profiles. Closed hollow profiles are not needed anymore and they are replaced with angle profiles.

According to presented theory of design for assembly and manufacturing components need to be simple. The hollow profile roller tracks are not considered to be complicated but due to the length of the profile it is challenging to manufacture them accurately. In prototype R2.4 the roller tracks are hollow profiles and they have inserted bushings which are welded to the profile. To achieve easiness for installation position of the bushing needs to be inside ± 0.2 mm tolerance through the whole 4 meter long profile. Fixing screws through the hollow profile is never optimal solution. Due to these reasons hollow profiles are replaced with angle profiles. Angle profile roller track provides simple connection interface with cross beams and self-supporting brackets.

Final design R2.5 uses hot rolled steel angle profiles as roller tracks. These profiles are according to Chinese GB standard. Installation is carried out in sequences. Cross beams are aligned with self-supporting brackets by using spring pins. Roller tracks are compressed against the block in cross beam. This design ensures that roller tracks are always on the right distance from each other. Symmetry has been used to make installation of cross beams and self-supporting brackets easier. Each cross beam is machined after welding and self-supporting brackets are cut by laser. These manufacturing methods ensure dimensionally accurate components. Figure 48 presents details of the connection.

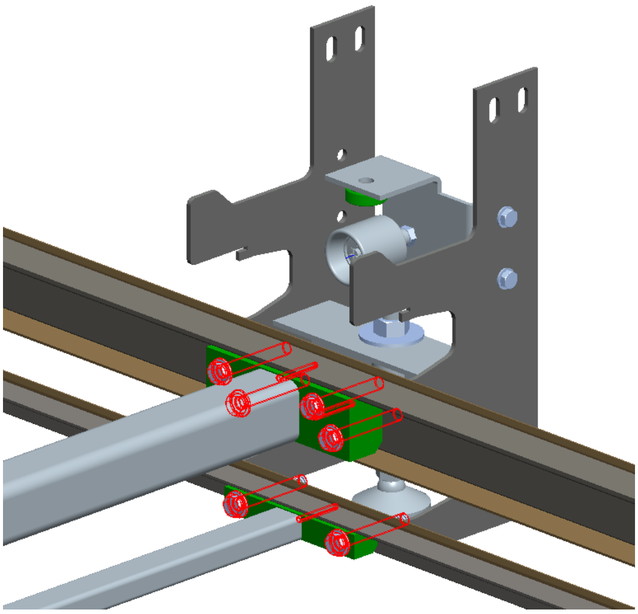


Figure 48. Connection between cross beams, roller tracks and bracket.

The upper roller track is fixed with four screws and according to the calculations, presented in appendix 8, safety factor is 2.9. These screws are placed off from the centerline so that each screw is only either under compressive or tensile stress. Guiding profiles for pallet rollers are simple bended sheet metal components. The upper nose profile works also as a counter guide for lower pallet. Both of the profiles are aligned also with the spring pins inserted through the roller tracks.

All four roller tracks of the middle section are connected to next module by machined steel blocks. The connection interface between roller tracks has a step to enable adjustment between modules. This design enables also flexible tolerances for the roller tracks. There is no need to tolerate the holes strictly due to the ability to adjust tracks. InnoTrack™ unit is designed to be installed indoors and there is no need to study thermal expansion for the structure. However due to the design the gap between the tracks would cover possible thermal expansion of the tracks. Details for the connection and the split are presented in figure 49.

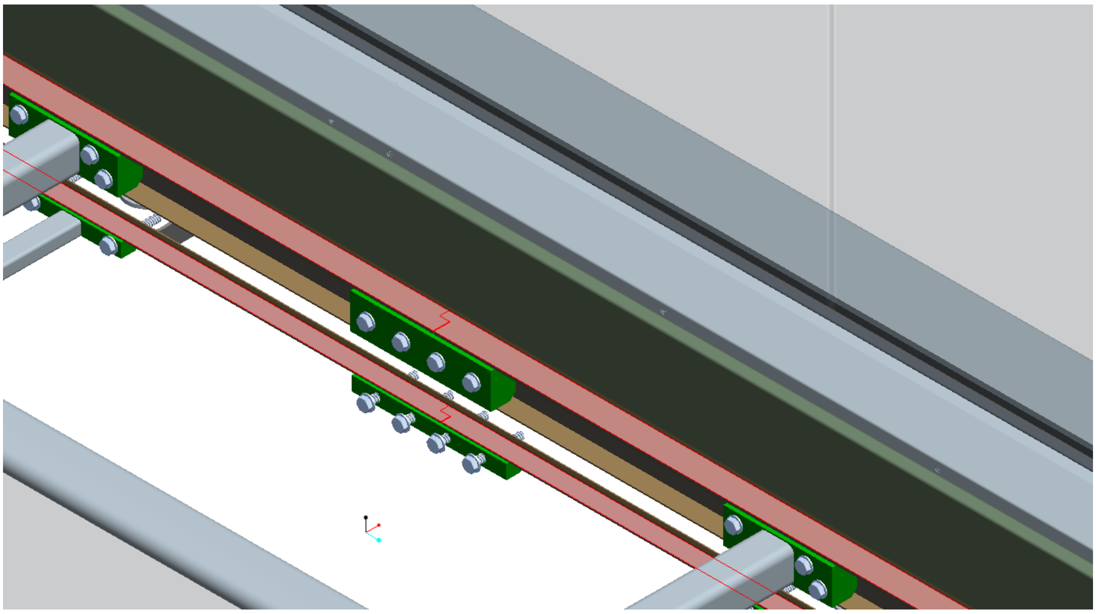


Figure 49. Connection between middle section modules.

Angle profile roller tracks are easier to manufacture compared to the hollow profiles as there are no welded components. Use of angle profile roller tracks enables also cheaper design for pallet guiding profile. To achieve needed ride comfort the running surface for the pallet needs to be controlled. The purchased samples for tests were bad quality and the hollow profiles were good example of the bad quality components that are available in China. Weight of the angle profile roller tracks is less than the hollow profiles. According to the 3D model the weight of the R2.5 design is 521 kg. Weight of the new solution is therefore 40 kg less than in the original design.

Balustrade and handrail guiding system

Balustrade glass panel is fixed with two aluminum die cast glass holders. The design uses same glass holder as the conventional units but the holder is a cut model. This means that bottom of the holder is machined. The glass holder needs to be cut to make space for the return side handrail. Conventional KONE autowalk AJV uses this cut design in its head sections. This ensures competitive cost for the glass holder. Due to the reason that the die cast glass holder requires more space for the fixing, the bracket is modified to be wider. R2.5 is therefore 47 mm wider compared to the original design. Wider bracket is also more rigid against balustrade load.

InnoTrack™ head modules needs to be installed at least 500 mm away from the wall. This is due to the reason that head sections needs to be accessible for maintenance. With new wider design the needed distance between wall and unit is 476.5 mm. Therefore distance between centerline of the unit and the wall is same as in original design. InnoTrack™ can be installed next to a wall if there is room for maintenance in head sections. Unit in metro Madrid, Spain is installed this way. In this case R2.5 design needs to be 23.5 mm further form the wall compared to the original. Due to the reason that autowalks are usually installed on airports or buildings with open space the 47 mm increase to width is acceptable.

Space efficiency is one of listed customer needs. This need is more related to height of the unit, especially travel height. It is more beneficial to extend width of the unit and use existing design for glass holder rather than design a new glass holder which is only used in InnoTrack™. According to authors knowledge current glass holder will be replaced with new design. Key dimensions for the glass holder are already known and therefore R2.5 has been designed to be also compatible with this expected new glass holder.

As mentioned the glass holder needs to be machined so that returning handrail fits in. Each self-supporting bracket has a support roller and guiding bearing for the handrail. These components are same as in original design. Difference is that there is only one guiding bearing per support roller. However there are now eight support rollers in one middle section instead of 4 like in original design. This is due to a reason that handrail would touch the bracket without support roller in each bracket. Travel line of the handrail is 25 mm lower than in original design. First handrail roller is lower and due to gravity handrail is dropped to correct line. Guiding components in head section remain same as in original.

Design for self-supporting bracket system in creativity step had handrail support roller with diameter of 60 mm. This roller is changed to one with diameter of 45 mm, the one used in original InnoTrack™. Space is needed as the chosen glass holder is bigger than the one designed in creativity step. According to the prototype tests two glass holders are required per self-supporting bracket. Therefore in cost wise it is beneficial to use existing and cheaper glass holder rather than new design. The chosen glass holder has high volume and cost is highly competitive.

Visual components

Conventional KONE escalator and autowalk units are using stainless steel as visual components. Stainless steel is considered to be appealing material. Final design for the self-supporting bracket system uses stainless steel sheet metal components for skirting, cladding, inner and outer decking panels. Raw price of the stainless steel is roughly 2.5 times more than raw price of carbon steel. Therefore only mentioned visual components are stainless steel and all fixing components are carbon steel. The material thicknesses of the components are same as in conventional units.

Design for skirting is based on a design that was made for conventional escalator skirting optimization project. Dimensions on the final design are determined according to the optimized skirting design. Differences are that in case of the self-supporting bracket system the longest span between support points for skirting is 790 mm as there are two fixing interfaces per bracket. These fixings are presented in figure 50. The counter guide profile is fixed to the lower end of the skirting profile. Together with the counter guide another bended angle profile ensures that the skirting is compatible with the EN 115-1.

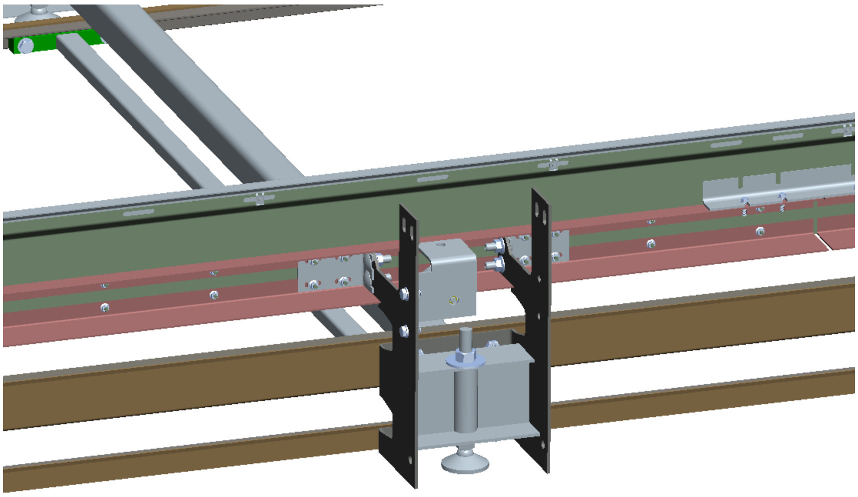


Figure 50. Skirting fixings

Inner and outer decking panels are basically same as in conventional units. The fixing method for both is same as in conventional units and also material thicknesses. The cladding is inserted between outer decking and angle profile in lower end. The angle profile is fixed to the brackets. The cladding lies on the angle profile which can be installed so that it is always few millimeters above the floor. Dimensions of the outer decking ensure that the cladding is always behind the decking panel. Details for this design is presented in figure 51

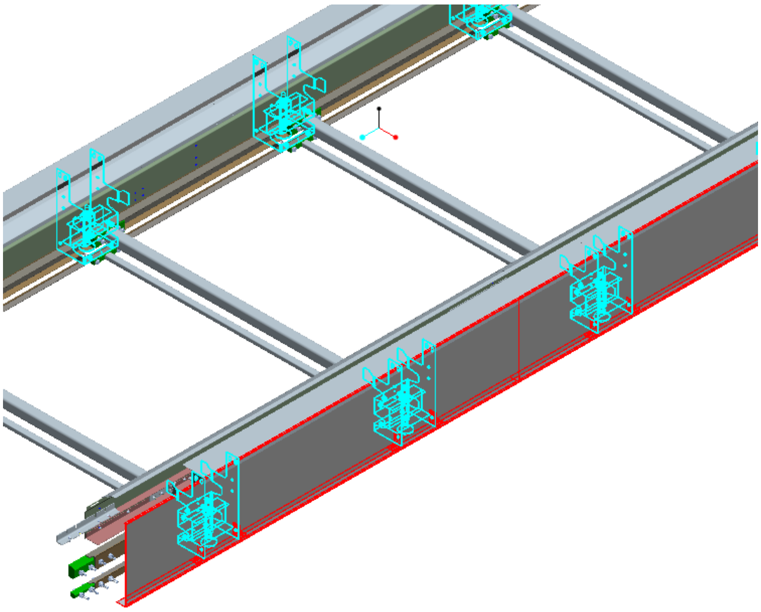


Figure 51. Cladding fixing

Module connection

Design to connect two middle section modules is analyzed earlier in this chapter. Connection between middle section and drive head module is done by using self-supporting bracket and machined steel blocks. This design ensures that the head modules are compatible with the components in middle section. Each machined block enables adjustment respect to roller track profile. Machining ensures sufficient manufacturing tolerances for connection blocks. Modifications in tension head and drive head are done so that the base steel frame is simply extended. Left and right hand sides are mirror copies from each other like in original design.

Design for steel frames in head sections are validated in previous test done in KONE reliability laboratory. Modifications for head sections are assumed to have minimal effect to the structure. Rigidity of the head section is assumed to be higher as the frame is longer.

4.4.3 Value for the customer

Provided satisfaction of needs

The final design R2.5 is graded by author. The given grades how well the structure is fulfilling the customers' needs are according to authors' knowledge. As mentioned earlier in this thesis satisfaction of needs is not unambiguous. To get defined results the grades for each function groups should have been asked from large group of customers. The given grades how well the structure is fulfilling the customers' needs are according to authors' knowledge. It is considered to sufficient method to grade function groups as mentioned. This is due to the reason that the requirements for the structure are more related to clauses in safety standard EN 115 than for needs depending on customers' opinions.

Customer needs are listed in the beginning of this thesis work. The final solution is compared to the original in terms of how well it fulfills the needs. Summary from the satisfaction is presented in table 17. Space efficiency is the only need where the new solution is giving less satisfaction for customer compared to original design. However this is acceptable due to the achieved cost reduction on the price of single glass holder. New solution has more components which makes installation more difficult. However at the same time the adjustable foot saves time as there is no need to prepare the floor. Therefore the new solution can be considered to be as easy to install as the original.

Achieved lower weight for the module is significant achievement. Aluminum had been chosen for the original unit for its light density. End result was not light due to the size of the truss profile. In self-supporting bracket system only needed components are continuous. This enables lighter weight even though the used material is steel.

Table 17: Satisfaction of needs compared to the original design

Customer needs	Self-supporting bracket system	Compared
Compatibility with EN 115-1	Supporting structure calculation & test	Same ▶
	Balustrade strength test	Same ▶
Configurable unit	Connectivity between modules	Same ▶
Light weight	Module weight 521 kg → 40 kg lighter	Better ▲
Space efficient solution	Ride height 200 mm	Same ▶
	Unit width → 47 mm wider	Worse ▼
Easy to assemble	Adjustable foots to align the system with floor	Better ▲
	More components compared to original	Worse ▼
Fine ride comfort	Steel tracks and guiding profiles	Better ▲
	Small deflections with passenger load	Same ▶
Appealing visual appearance	Stainless steel for visual materials	Better ▲

Used resources

Quotations for the component costs are provided by KONE sourcing department. Quotation costs are related to three volume scenarios. Scenarios are one, five and ten units per year. Cost comparison in this chapter uses quotation costs according to the volume of one unit per year. According to this quotation cost the R2.5 design is -67.60 % cheaper than the original design. The main reason for this is the simplicity of the components. Most of the components are manufactured from Q235B steel which ensures competitive raw material price for the components. Manufacturing methods are kept as simple as possible. Cost comparison between function groups is presented in figure 52. Sum of the costs for original solution are 100 % and for R2.5 design 32.40 %.

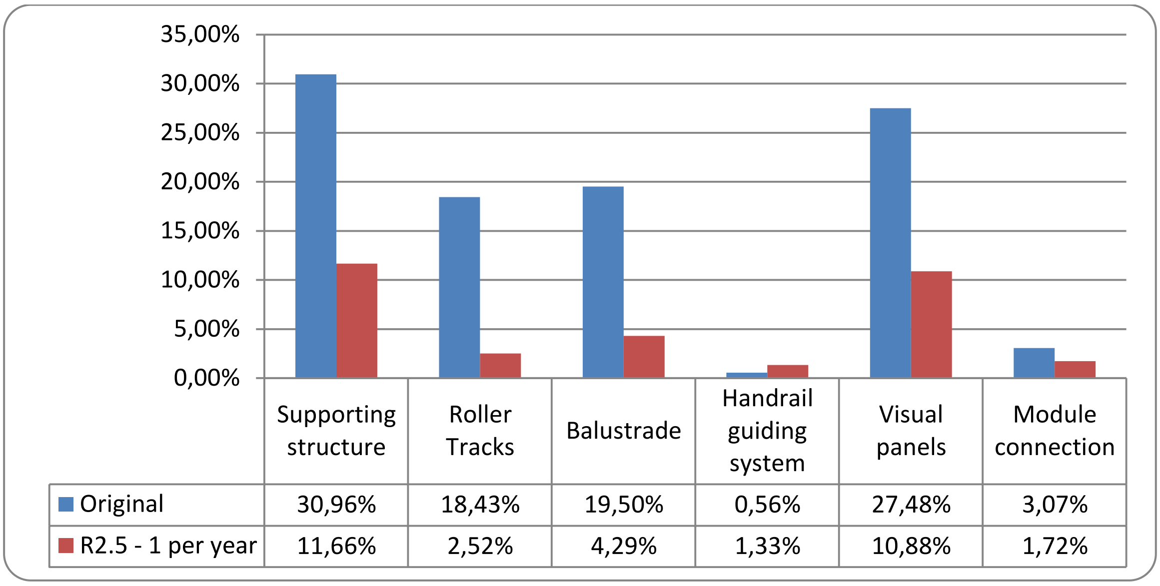


Figure 52. Cost comparison between function groups

For R2.5 the most expensive function groups are supporting structure and visual panels. Visual panel group is the second biggest cost for R2.5 design and the reason for this is clear. Stainless steel as a raw material is expensive. Cross beams and self-supporting brackets are included to the supporting structure group. These components are the most expensive but at the same time these components have the major task to provide the supporting structure for the unit. The design to use angle profile roller tracks is cost competitive solution as the costs for roller track components are relatively small. Costs for balustrade group are also in competitive level. However the costs for this group do not include any costs from the brackets. Brackets are part of the balustrade system but as the major task for the brackets is the supporting structure the costs are not divided.

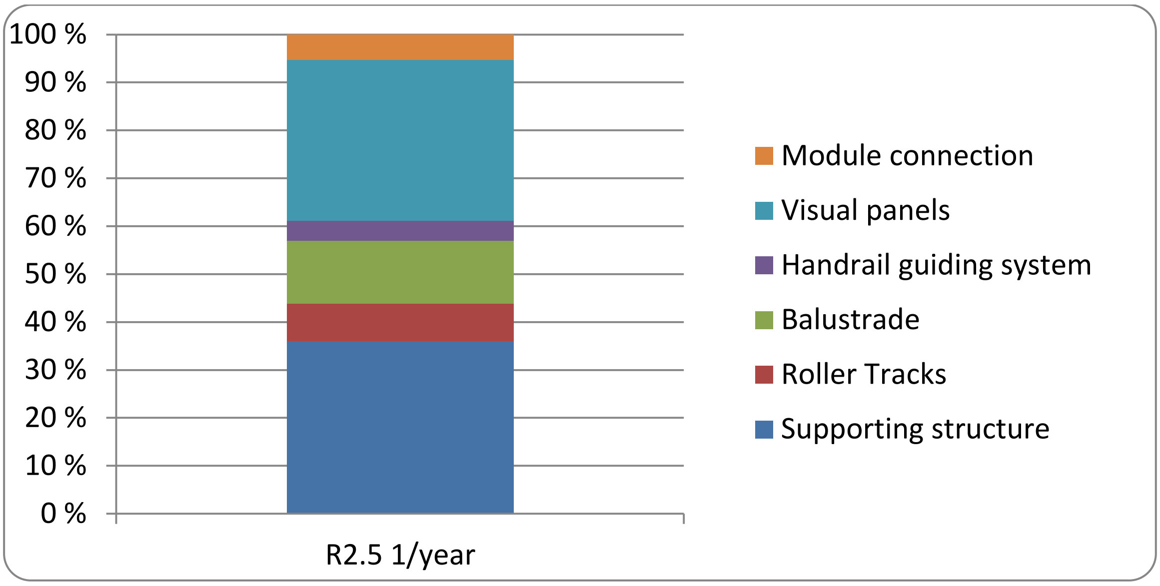


Figure 53. Cost model for R2.5, one sold unit per year

Previous figure 37 in chapter 3.5.1 presents cost for three different volume scenarios. According to the presented results the cost of the middle section module would decrease by -1.44 % if the yearly volume would be five sold units instead of one. Respectively the cost reduction is -3.29 % if the volume is ten units per year. Reference unit is 48 meters and it has 10 middle section modules and respectively ten units would have together 100 middle section modules. Unit volume has higher effect to the costs in original design. It can be concluded that the costs for the components are already close to raw material price. According to the results the cost reduction of a one middle section module is -67.60 %. In complete unit this would represent -13 % cost reduction when the unit is 48 meters long.

Installation time of the self-supporting bracket system is considered to be same as in original unit. This assumption is based on the tests done for the self-supporting bracket system prototypes. Some key components in self-supporting bracket system are fixed to each other with screw fixings. Self-supporting brackets, cross beams and roller tracks are all connected to each other with screws. Compared to the original design these screw fixings are increasing the installation time. Original solution is integrated structure and therefore the installation is straight forward. On the other hand self-supporting bracket system has adjustable foot and there is no need to glue a running track on top of the roller track. There is no exact data available for the installation time of the original unit, only raw estimations for each segment. Based on this estimation, preparation work and gluing of the running tracks takes alone 16 % from the installation of complete unit. Therefore it is concluded that the self-supporting bracket system requires same time as the original unit.

Manufacturing tooling costs for R2.5 design are minimal, only 8.6 % from the costs of original unit. When comparing the manufacturing tool costs one should keep in mind that the tooling costs for original unit are based on quotation from Chinese supplier. It is assumed that the mould costs in Europe are higher. Used resources to achieve the current accuracy level to manufacture the aluminum truss profile are assumed to be even higher than the cost of the mould.

The first design for the self-supporting bracket system had same support roller as the conventional units. This roller diameter is 60 mm and it is 16.5 % cheaper compared to the chosen one. This roller with diameter of 60 mm would not require investments for mould. However this roller was replaced due to the reason that with smaller roller the system can use same glass holder as the conventional units. It is beneficial to use the smaller roller with diameter of 45 mm as the die cast mould for the new aluminum glass holder is 2.7 times more expensive than the mould for support roller. According to the quotations the conventional glass holder is also cheaper than the one designed in creativity step.

Gained value

Value comparison between original design and R2.5 is presented in figure 38 on page 63. This comparison shows that R2.5 provides better value in all three categories. This is even though the original design middle section provides relatively good satisfaction to the customers' needs. If comparing the deflections of the balustrades between R2.5 and original unit the original design has better performance. Under same static load the deflection of the balustrade in original unit is less. However both designs are in compliance with the EN 115-1 standard. Task for the structure is to be in compliance with the standard and therefore self-supporting bracket system provides same satisfaction but with lower costs and this inevitably means higher value.

Investment for extruding mould is not beneficial if component volume is low. In this context of InnoTrack^{TM} the extruding tools for the aluminum profile are providing poor customer value. Self-supporting bracket system has minimal costs for tooling compared to the original design. Tooling costs for R2.5 are 2.04 % of the cost of original design. The low cost for tooling explains the high increase of value in manufacturing tool category.

The original design provides good value to the customers' needs in terms of fulfilling the requirements in EN 115-1. According to given grades the original design is not providing proper satisfaction for the need to provide desirable appearance with visual components, materials and shape. The extrusion mould determines the shape of the profile and it can be changed only by investing for new mould. Head sections are using stainless steel plates to cover the newel. The aluminum profiles are different color than the stainless steel covers. This can be considered to be unwanted aesthetic feature. R2.5 uses stainless steel plates as visual components. Stainless steel is considered to be more desirable material than aluminum. Visual panels have 33.57 % share of the costs for middle section module. This is the second most expensive cost group. These costs are justified due to the reason that visual panels have great effect to the aesthetic needs. Costs of these panels are directly focused to provide satisfaction to customers' needs.

5 DISCUSSION

KONE InnoTrack^{TM} moving walk is a configurable unit which is built from three different basic modules. These modules are middle section module, tension and drive head module. For this master thesis middle section module is re-engineered according to value analysis process. As part of the value analysis process the original structure is studied and analyzed. Customer needs for the structure are gathered. Different design variations are created and judged by the value that they give to the customer. Most valuable design is validated by executing prototype tests. Prototype design is modified according to the performed tests and final design is presented.

5.1 Value for the middle section

Customer needs are gathered by author and employees in KONE technology organization. Listed needs are: Compatibility with EN 115-1 standard, configurable unit, light weight, space efficient solution, easy to assemble, fine ride comfort and appealing visual appearance.

Self-supporting bracket system for moving walk is the final result from the value analysis process. Over all new design provides higher satisfaction to the customer needs when comparing to the original design. Need for space efficiency is the only need where the new solution is providing lower satisfaction than the original solution. This is due to the reason that the middle section module is 47 mm wider compared to the original. Needs for configurability and compatibility with EN 115-1 standard are same as in original. New design is considered to be as easy and fast to install as the original. Structure has more components than the original structure but on the other hand it has features to enable straight forward installation. One of these features is the possibility to align the height of roller tracks respect to the floor with adjustable foot. New structure uses mainly steel components but the structure is lighter than the original structure. This is a major benefit for the structure as raw of steel is roughly three times less than aluminum. As mentioned the new design uses steel components and therefore running and guiding surface for pallets are also steel. Squeaking noises from pallet rollers touching aluminum profile are no longer an issue. Also deflections of roller tracks are as small as they are in original unit. New design uses stainless steel components as visual material and these are considered to be more desirable for customer.

Used resources are compared in three categories. These categories are component costs, needed investment for manufacturing tooling and installation time. Component costs for the middle section module are -67.70 % from the original costs if yearly volume is 1 unit. This reduction is -13.30 % in complete unit level, when sold unit is 48 meters long. Component costs are calculated also for yearly volumes of 5 and 10 units per year. The reduction in these volumes is not dramatic which means that the costs are already close to the raw material price. Self-supporting bracket system requires only one mould. This mould is for plastic handrail support roller. Investment costs for the mould are 8.60 % from the costs that manufacturing tools would cost for original design in China. Installation time is assumed to be same as in original. The original unit is integrated structure but there is no possibility to align the unit respect to the uneven floor. New design does not need shimming or gluing which saves time. On the other hand self-supporting bracket system has more components and requires more time to adjust the components. These mentioned installation sequences are considered to take the same amount of time.

Value is compared in three categories based on the used resources. These categories are component costs, needed investment for manufacturing tooling and installation time. Self-supporting bracket system gives higher value to the customer in all three categories when comparing to the original design.

5.2 Complete InnoTrack™ unit by using self-supporting bracket system

Presented new design for InnoTrack™ middle section module is detailed. Design is validated with tests and structural strength calculations. Design to connect middle section modules together or with head section modules is not validated. Module connections are designed with 3D and based on the knowledge of author and employees of KONE technology organization all three connections are feasible.

Escalator and moving walk safety standard EN 115-1 does not determine any limits for the balustrade deflection under balustrade load. Balustrade deflections for self-supporting bracket system are measured to be in same level as in original design when static load is applied. Balustrade system is not designed to withstand reciprocating load and when reciprocating load is applied the balustrades on both sides are prone to wave. The movement of the balustrade will transfer through the structure to the balustrade on the other side. During the tests failures where not encountered and described reciprocating load case is not considered to be in the scope of normal use of a moving walk. However this phenomenon might give bad user experience for the end user and a decision should be made if the movement is acceptable for KONE product.

Root cause for the described phenomenon of balustrade under reciprocating load is to be defined before further development. Based on studies done in KONE escalator laboratory the root cause is not clear. During the tests it was discovered that the structures behavior changes when load is applied on roller tracks. When load is applied on roller tracks the waving is more restrained. Occurring deflections on the structure are studied with dial indicators. Small deflections are measured but none of these can be identified to be the single root cause. Small transformations occurred also on the adjustable foot while balustrade was under reciprocating load. Based on the prototype behavior the current understanding is that the balustrade waving is a sum of all small deflections on the structure. During the tests the whole middle section module was also moving respect to the floor. Described movement could cause unexpected failure modes for the unit.

Development plan for the structure depends on the decision what is acceptable movement for balustrades when reciprocating load is applied. Most effective way to increase the rigidity of the structure is to decrease the dimension between each self-supporting bracket in longitudinal direction. Currently the span is 1016 mm and by decreasing the dimension with 20 % the effective load per bracket will be decreased by 20 % as well. Rigidity against balustrade load would be increased at the same time. Additional pair of brackets would increase component costs for single middle section module with 10 %. This design increase also installation costs. However as mentioned the root cause for balustrade waving is not clear and it cannot be said for sure that the additional bracket would fix the problem.

Design to connect middle section module to head sections is presented in this thesis. The design is not as detailed as the actual middle section. Functionality test should be executed for the complete unit which is using self-supporting brackets. Based on this test the structure and connections between each module can be validated. To validate the connection it is enough to have the head section modules with returning stations. Use of self-supporting bracket system requires also slight modifications to the newels in head sections. Current solutions can be modified to be used with self-supporting bracket system but according to authors knowledge it would be more beneficial for the unit if handrail drive system would be re-engineered. Currently InnoTrack™ can run only one direction because handrail cannot be driven to both directions.

5.3 Development ideas

Use of extruded aluminum profile as a truss for moving walk sets strict boundary conditions for head section. In case of InnoTrack™ this extruded profile is limiting the options to develop the head modules. Self-supporting bracket system provides an alternative solution. Connection between the bracket system and head modules can be modified to give better satisfaction for customers.

Design for handrail drive can be modified so that the unit could be driven both directions. Currently the problem is that the handrail drive does not have enough friction between the drive wheel and handrail. One possible option is to implement design changes for balustrade so that there is enough friction. This would require a handrail bow which is fitted inside of the newel. Lack of free space inside of the newel is currently preventing this design modification. Another option is to fit linear handrail drive inside of the newel. Linear handrail drive would be more space efficient decision.

The concept of self-supporting bracket system could be expanded from InnoTrack™ to conventional moving walk units. Head sections would be as in conventional units and middle sections would be according to the self-supporting bracket system. Head sections would be in normal size pits and the middle section components in reduced pit. The benefit from this approach is that there is no need for heavy truss structure. On the other hand the requirements for building would be stricter.

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APPENDICES

Appendix 1. Original design of InnoTrack^{TM}

ORIGINAL DESIGN ANALYSIS

Original solution, supporting structure

Extruded aluminum truss profile and ThinReverser^{TM} system are the key components for flat design. There are lots of functions integrated to the extruded aluminum profile. The design is simple but manufacturing of the profile is challenging. Tolerance requirements are just too strict for the current technology. Due to the big size of the profile current supplier is not able to fully meet these tolerance requirements. Lack of manufacturing precision has caused problems in the field. The big size of the profile is limiting the number of possible suppliers. Material properties of aluminum enable the use of extruding technique. Compared to steel it is well known that aluminum is more suitable for extruding. Due to the big size of the profile, light density material is required. In this case however the profile is still heavy as it weights over 110 kg. Price of raw aluminum is higher than steel. In China the aluminum is roughly 3 times more expensive than steel. Price of aluminum is also more depended on global economy.(KONE Corporation c, 2011)

Aluminum truss profile requires careful preparations for the floor before installation. Profiles are leveled with shim plates. Cross beam links left and right side profiles together. Correct length of the beam is crucial for the device. It keeps left and right roller tracks always on right distance from each other. The cross beam is welded structure and it has also strict tolerances. There have been some cases that cross beams have lacked tolerances and they have caused problems on the field. However it is feasible to control the tolerances on the beam. (KONE Corporation c, 2011)

Original solution, roller tracks

Under the continuous pressure from rollers running on the track, aluminum starts to deform. Pallet rollers are making also squeaking noises when they are touching guiding edge of the aluminum profile. These issues were fixed by adding a steel running track on top of the track and by lubricating the aluminum guide to reduce the noise.

Original solution, balustrade

Balustrade glass panel is fixed to aluminum profile and it is tested to meet requirement in EN 115-1. However the standard doesn't specify the limit for balustrade displacement under the load test. According to balustrade strength test done for InnoTrack^{TM} the balustrade deflects less than conventional KONE autowalk or escalator.

Original solution, handrail guiding system

Handrail guiding system is simple. The support roller is fixed to aluminum profile and guiding bearings are fixed to the pressure plate. The longitudinal aluminum profile enables long span between the support rollers. Span is 2032 mm and in conventional moving walk or escalator the span is usually less than 1200 mm. Longer span means less rollers and supporting bearings. Extruded skirting profile is easy to remove and therefore handrail can be changed easily.

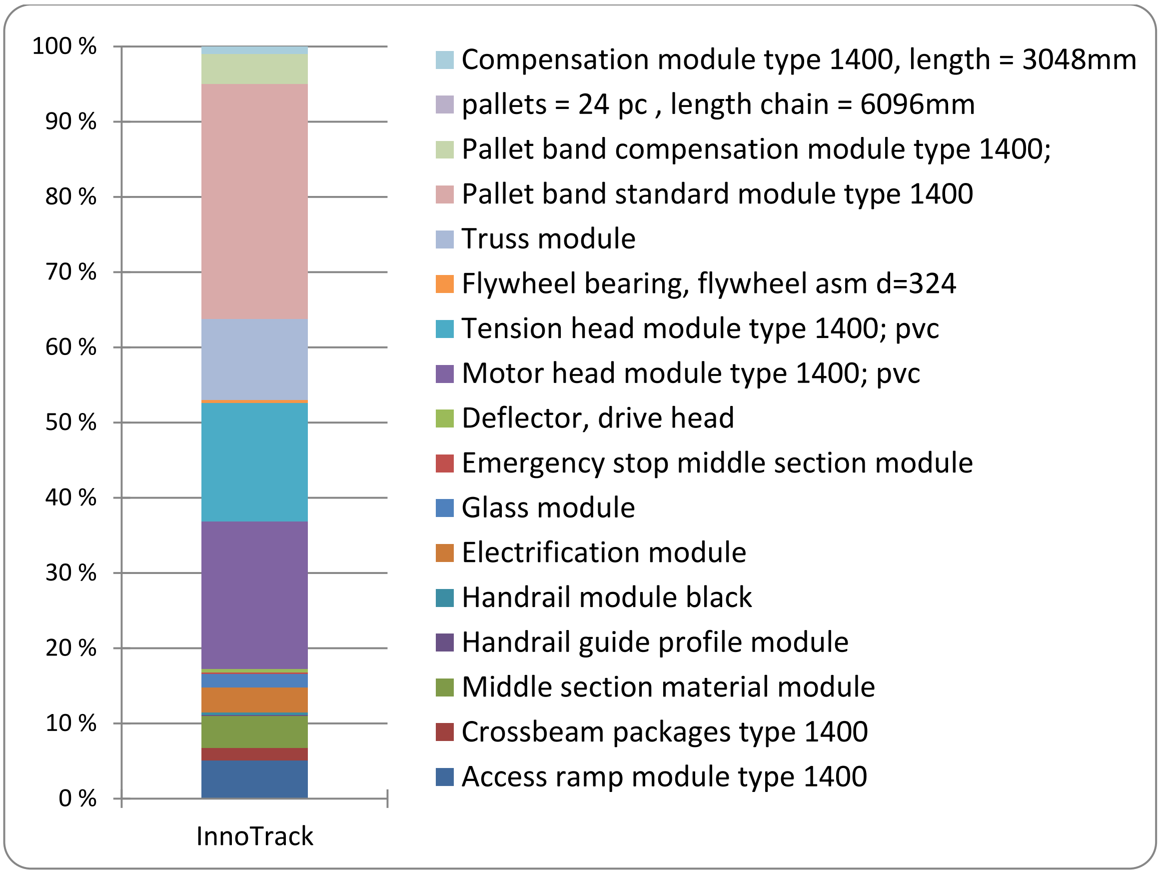
Original solution, visual components

Extruded aluminum profile is visual component. Color of anodized aluminum might vary little if the profiles are from different patch. The color difference between aluminum profiles is causing problems in the field as the customer is not accepting any differences. The skirting profile is also manufactured from aluminum and by using extruding technique. Skirting profile is also anodized and has the same color issue as the truss profile. Attractiveness of the visual appearance of InnoTrack^{TM} can be argued if it is concerned to be appealing or not. The usual locations for autowalks are airports or train stations. Constructors and architects usually prefer stainless steel instead of aluminum. With the current manufacturing method it is expensive and challenging to modify the visual shape of the middle section module.

Original solution, module connection

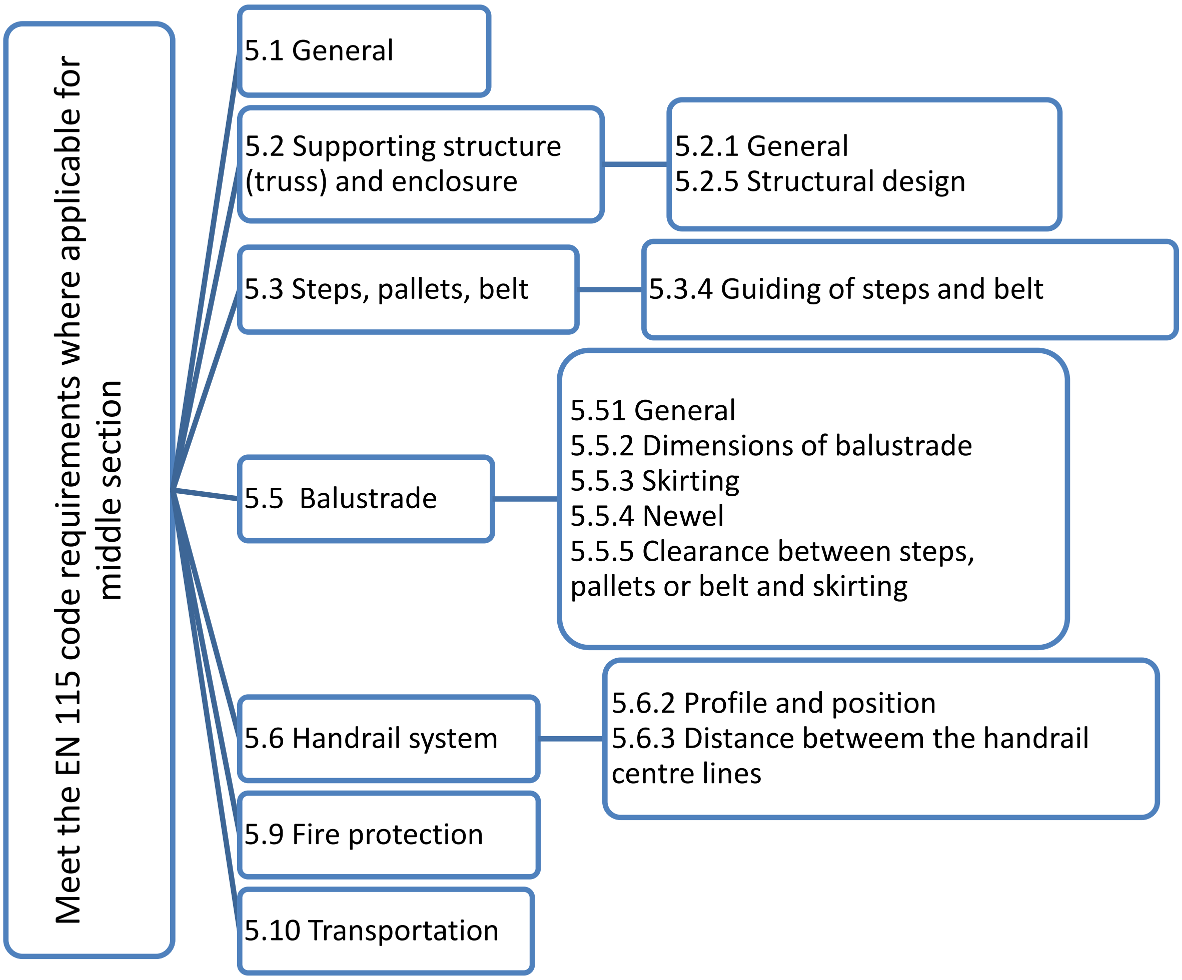
Despite the problems with aluminum truss profile it enables functionality of the middle section. Most of the functions are integrated to the profile which makes middle section installation fairly easy. Connection between middle section modules is fairly simple and it can be said that two modules are fairly easy to connect from design point of view. Differences between profiles along the unit are however causing problems. Installation of the unit starts from the drive head and continues to the tension head. Due to the installation sequences length differences accumulate to the tension head and are causing problems on site. (KONE Corporation c, 2011)

COST MODEL OF COMPLETE INNOTRACK™ UNIT

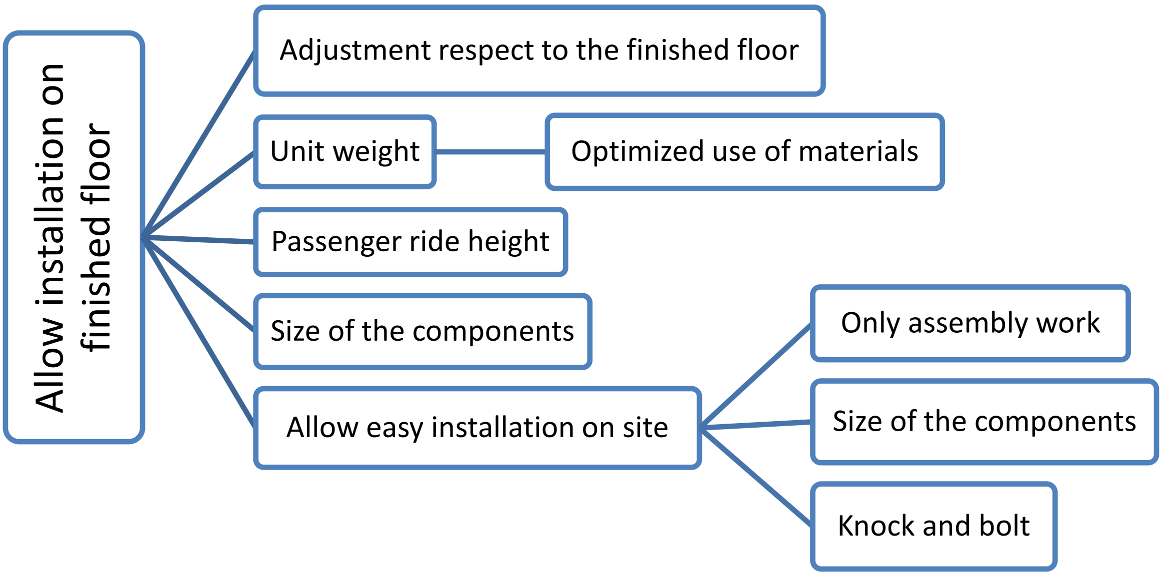


Appendix 1 figure 1. Cost model of complete InnoTrack™ unit

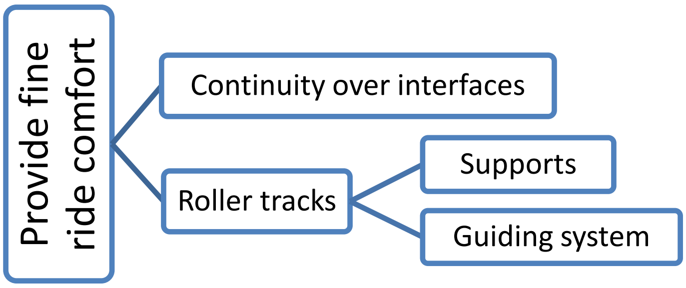
Appendix 2. Value trees



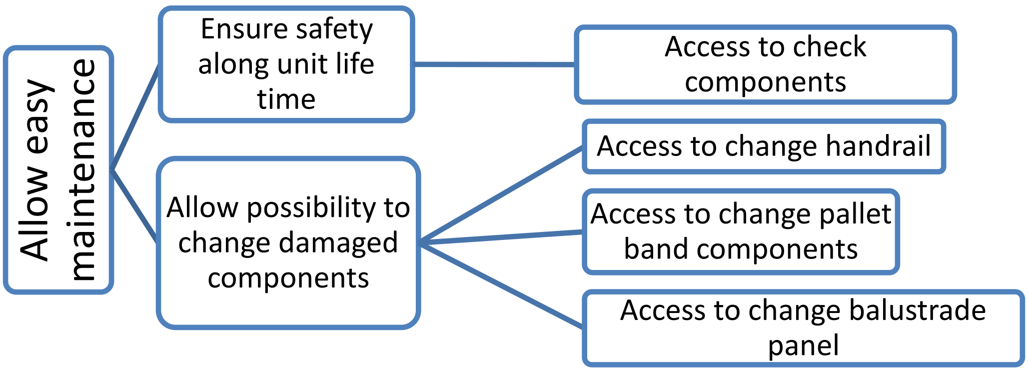
Appendix 2 figure 1.



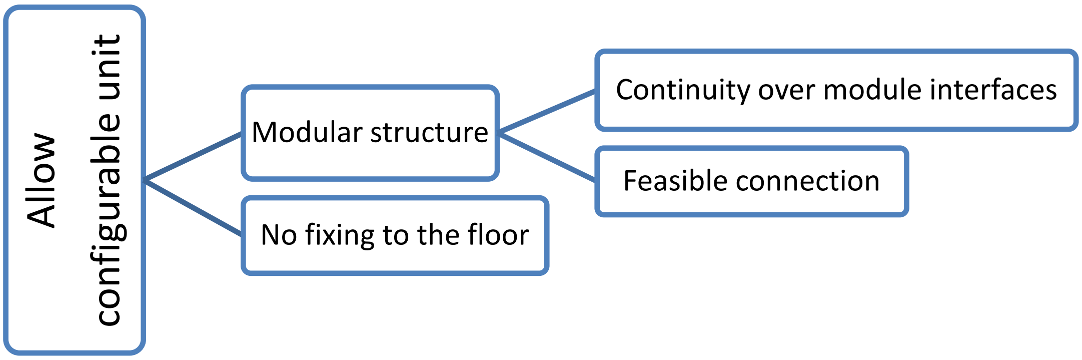
Appendix 2 figure 2.



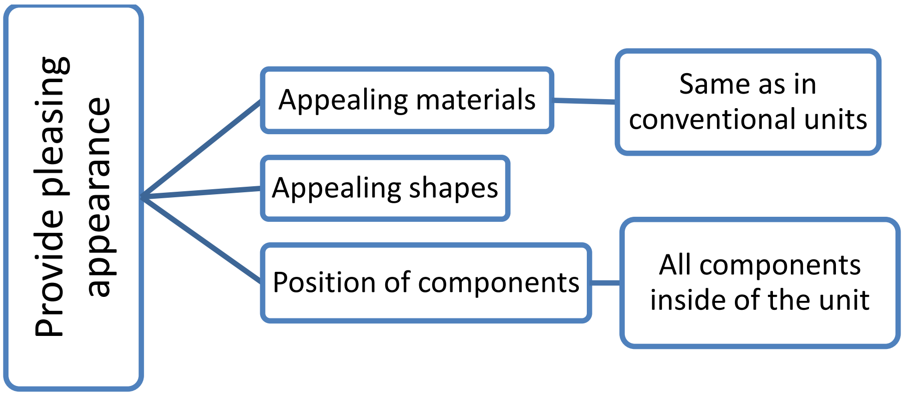
Appendix 2 figure 3.



Appendix 2 figure 4.



Appendix 2 figure 5.



Appendix 2 figure 6.

Appendix 3. Analytic calculations

RATED LOAD

Rated load for InnoTrack™ middle section is calculated according to equation.

$$F_{RATED} = 5000\frac{N}{m^2} \cdot A_{nominal} + m_{Deadweight} \cdot g$$

Given values:

Nominal area	$A_{Nominal}$	$5.6m^2$
Dead weight	$m_{Deadweight}$	1072kg
Acceleration of gravity	g	$9.81m/s^2$

$$F_{RATED} = 5000\frac{N}{m^2} \cdot 1.4m \cdot 4m + (560kg + 32kg \cdot 16) \cdot 9.81\frac{m}{s^2} = 38516.32N$$

REACTION FORCES FROM BALUSTRADE LOAD

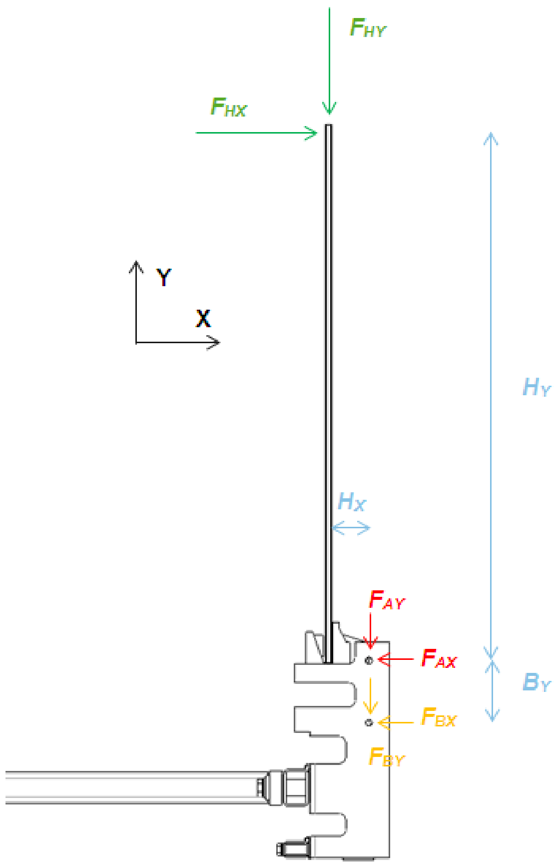
Load from the top of the balustrade is causing reaction forces on the fixing point of the glass holder. Reaction forces on these holes are calculated according to the static equilibrium.

$$\sum F_X = 0$$

$$\sum F_Y = 0$$

$$\sum M_A = 0$$

Load case is for solutions 2 and 3. Reaction forces in the glass holder fixing points. Free body diagram is presented in appendix 3 figure 1



Appendix 3 figure 1. Free body diagram.

$$F_{HX} = 600N$$

$$H_X = 65.5mm$$

$$F_{HY} = -730N + \left(21.740549kg \cdot 9.81\frac{m}{s^2}\right) = 963.275N$$

$$H_Y = 859mm$$

$$B_Y = 100mm$$

$$F_{AX} + F_{BX} + F_{HX} = 0$$

$$F_{AY} + F_{BY} + F_{HY} = 0$$

$$F_{HY} \cdot H_Y + F_{HX} \cdot H_Y + F_{BX} \cdot B_Y = 0$$

$$F_{AX} = 6371.845N$$

$$F_{AY} = -471.637N$$

$$F_{BX} = -5771.84N$$

$$F_{BY} = -471.637N$$

Appendix 4. Creativity step calculations

SOLUTION 1

Aluminum truss profile deflection

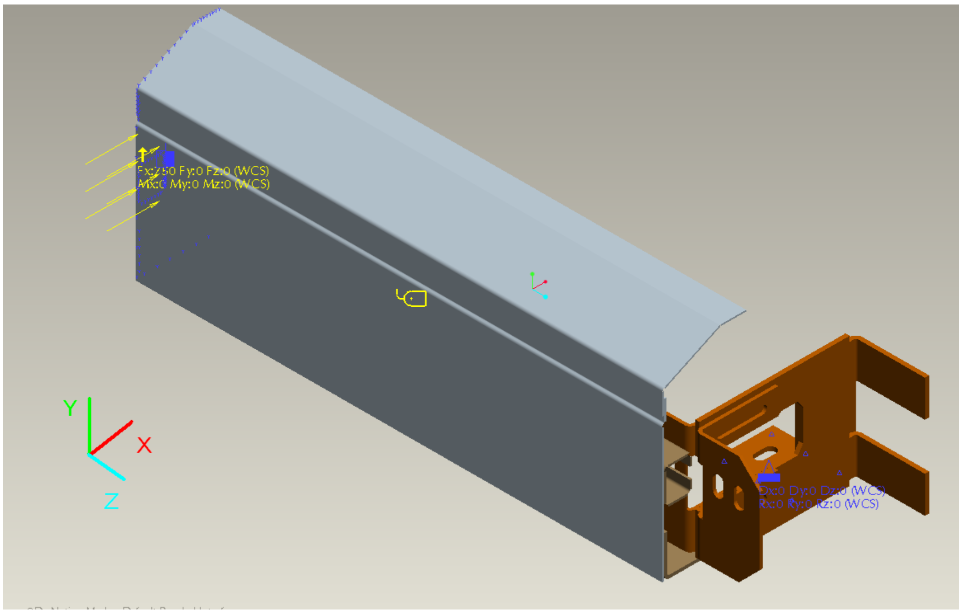
The aluminum profile is assumed to work as a beam with two fixed support points. Inertia properties are taken from PRO/Engineer.

$$f_m = \frac{Fl^3}{384EI} + \frac{16368N \cdot (4000mm)^3}{384 \cdot 70000MPa \cdot 1.7920362 \cdot 10^7 mm^4} = 2.281$$

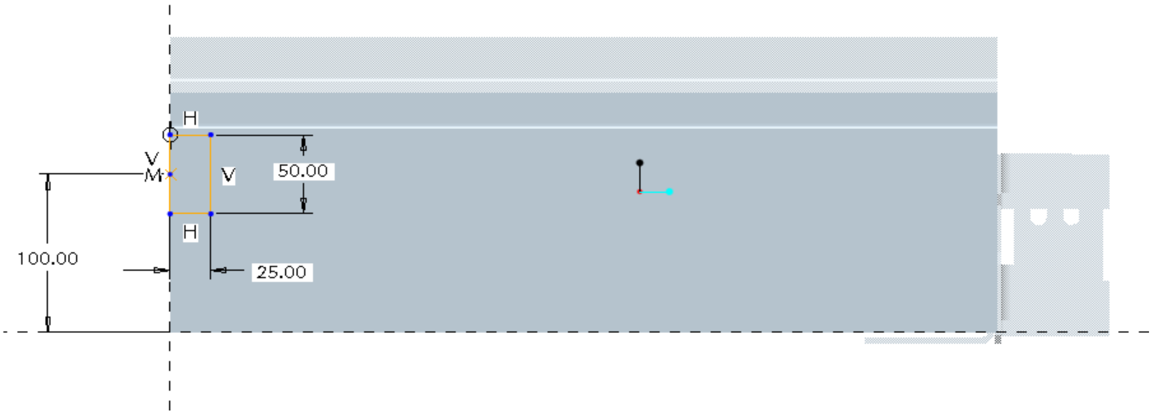
F is the load applied to the beam, l is the length of the profile, E is the elastic modulus of aluminum and I is the moment of inertia.

Skirting displacement - Calculation model 1 and results

Calculation model for skirting displacement is introduced in appendix 4 figure 1. The calculation model uses symmetry of the design and it is one fourth of the actual skirting assembly. Calculation model has one constraint in the support bracket where assembly is fixed to the aluminum profile. This constraint has all six degrees of freedom fixed. Another constraint is a mirror constraint in the free edge of the skirting profile. Static load is applied in square area of 12.5mm^2. Load area is the assumed weakest point and its location is presented in appendix 4 figure 2. Load of 750N is applied along X-axis. Each component is steel with elastic modulus of 199948 MPa and Poisson ration 0.27.

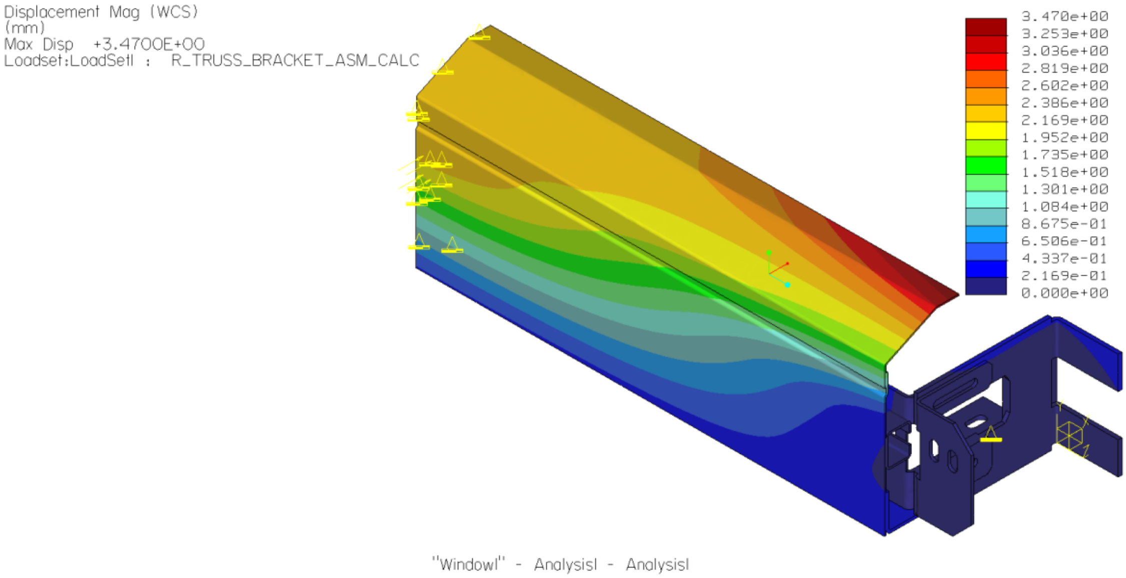


Appendix 4 figure 1. Calculation model for skirting load



Appendix 4 figure 2. Location of the load

Meshing is done with auto mesh tool in PRO/Engineer Mechanica tool. The calculation model has 14820 solid tetra elements. PRO/Engineer uses linear approach to calculate and stress error percentage of the calculation model is 8.25 %. Results are presented in appendix 4 figure 3 and the maximum displacement is 3.470 mm.

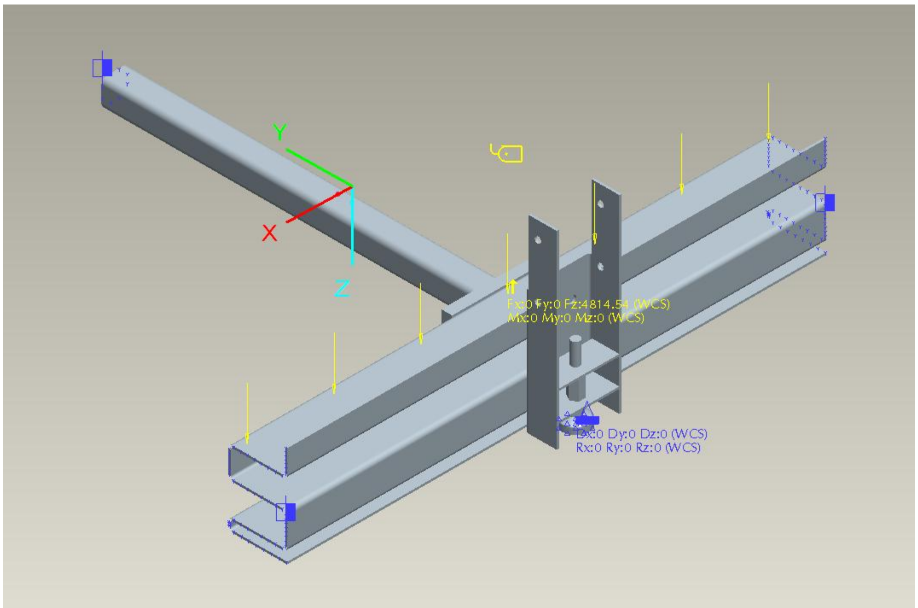


Appendix 4 figure 3. Maximum skirting displacement 3.470 mm

SOLUTION 2

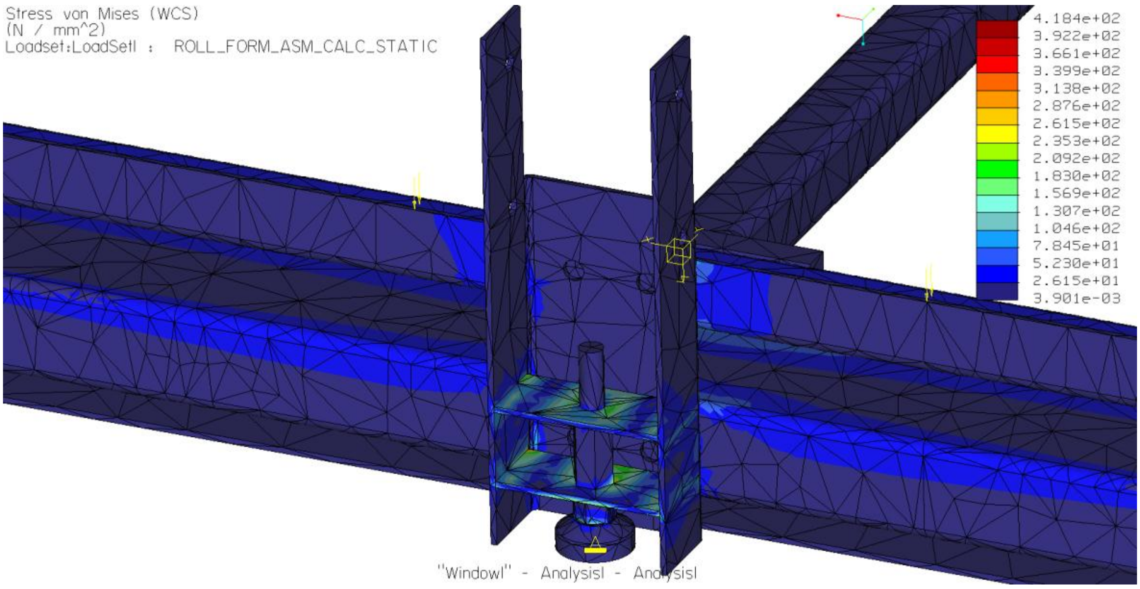
Rated load - Calculation model 2 and results

Calculation model 2 is to calculate stresses and displacements when rated load is applied. Calculation model uses symmetry and is one eight of the middle section. In the model there is one bracket and 1000 mm section from the roller track. Cross beam is half from the original length. There are together three mirror constraints one at the free end of the cross beam one in both ends of the roller track. Adjustable pad has a fully fixed constraint. Rated load is distributed on the upper surface of the upper roller track. Rated load is divided by eight because of the symmetry and its value is 4814.54N. Load is effecting in the direction of positive Z-axis. Each component is steel with Elastic modulus of 199948 MPa and Poisson ration 0.27. Calculation model is introduced in appendix 4 figure 4.

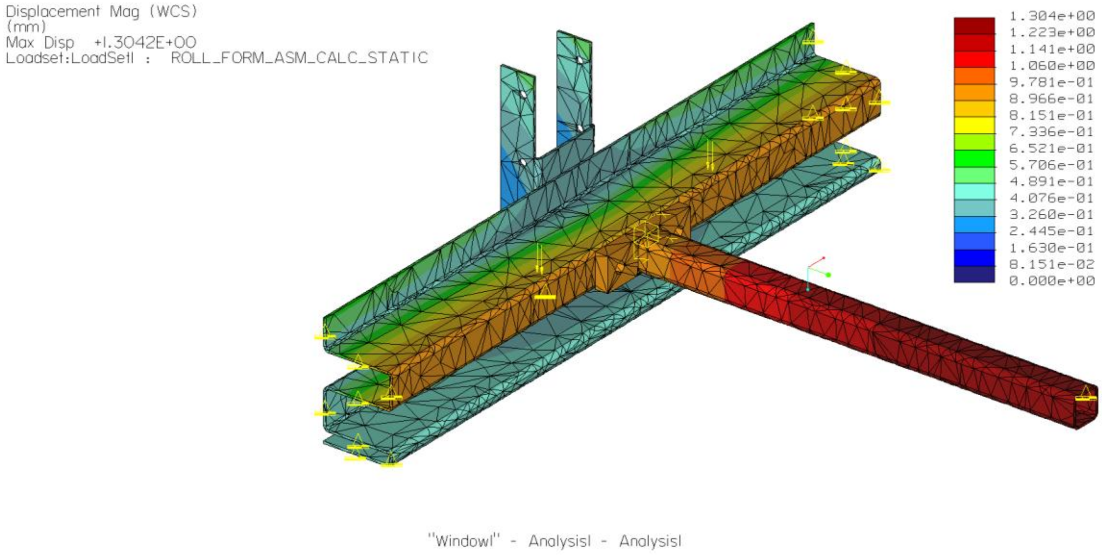


Appendix 4 figure 4. Rated load calculation model for solution 2

Meshing has done with auto mesh tool in PRO/Engineer Mechanica tool. The calculation model has 13680 solid tetra elements. PRO/Engineer uses linear approach to calculate the results and stress error percentage of the calculation model is 5.34 %. Results from rated load calculations are presented in flowing figures.



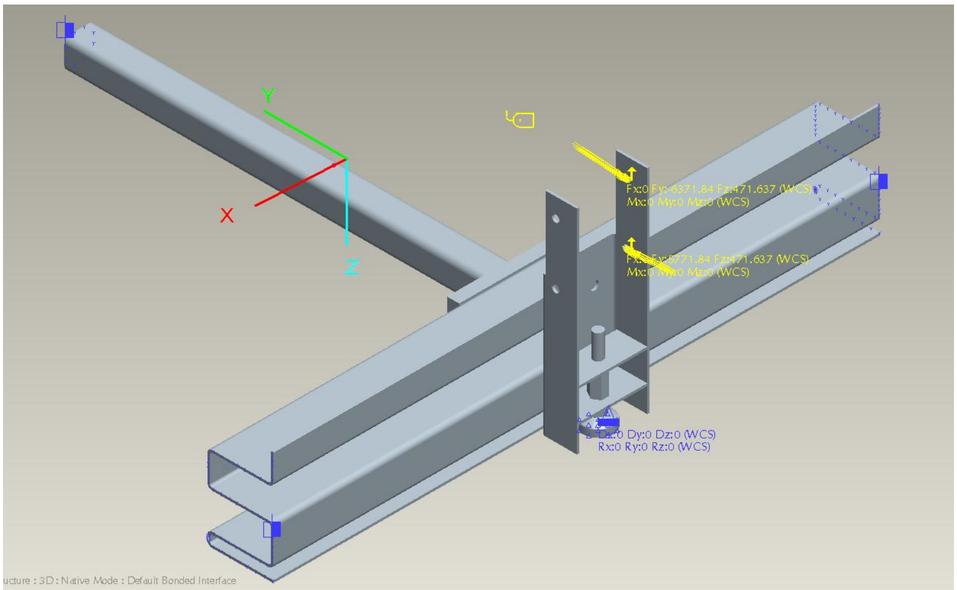
Appendix 4 figure 5. Solution 2 - Static load, Von Mises stress



Appendix 4 figure 6. Solution 2 - Static load, Displacements

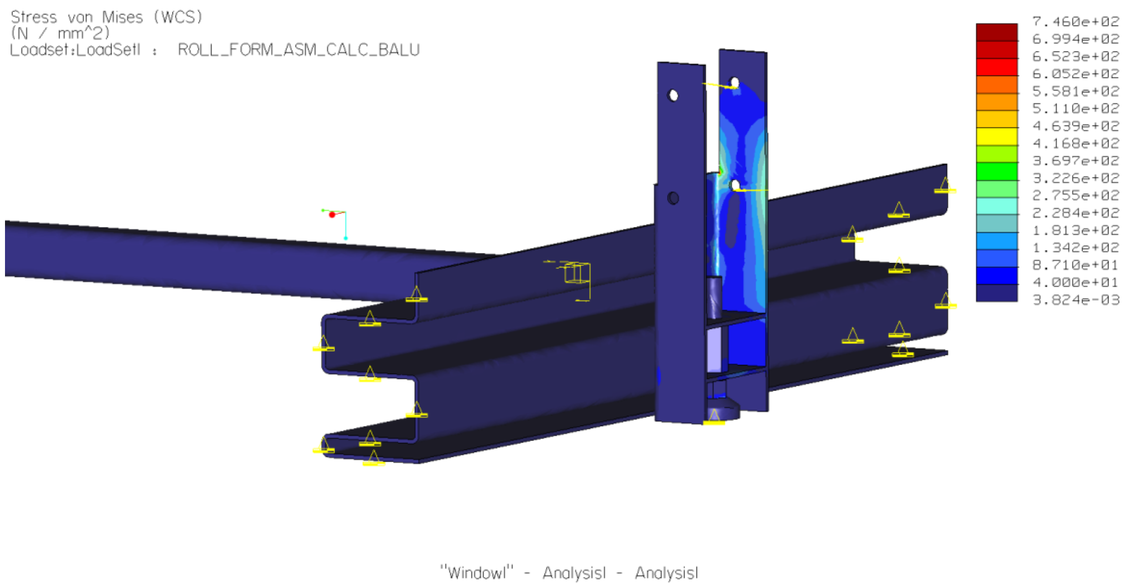
Balustrade load - Calculation model 3 and results

Calculation model 3 is to calculate stress and displacements when balustrade load is applied. Constraints and material properties in calculation model 3 are equal with the calculation model 2. Balustrade load is applied to the fixing holes of glass holder in supporting bracket. Reaction forces of the holes are calculated by using static equilibrium. Load on upper hole is -6371.84 N to the direction of Y-axis and 471.637N to direction of Z-axis. Load in lower hole is 5771.84 N to the direction of Y-axis and 471.637N to direction of Z-axis.

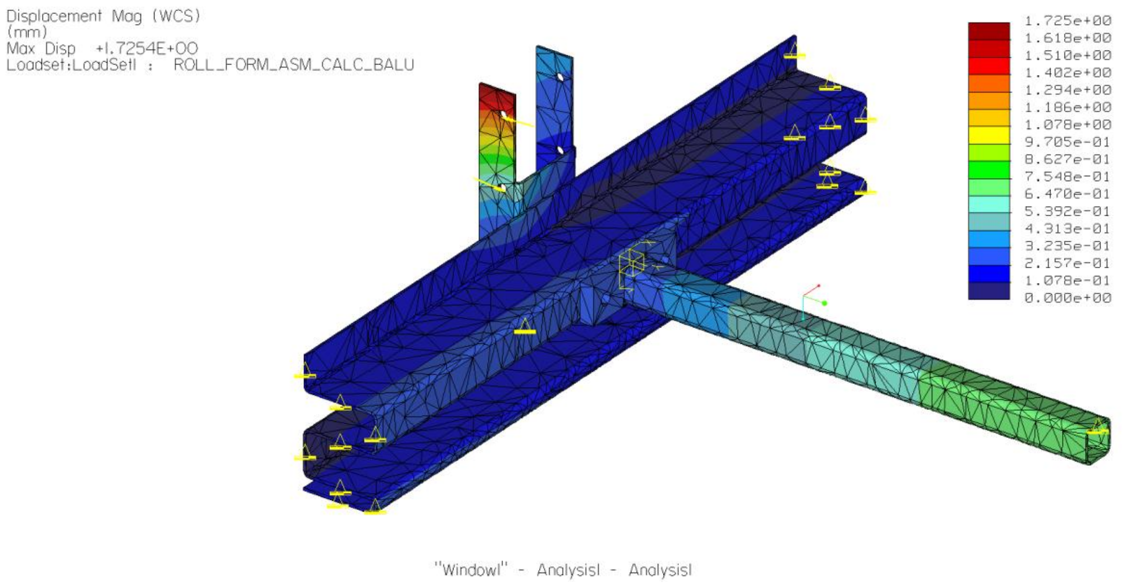


Appendix 4 figure 7. Balustrade load calculation model for solution 2

Meshing has done with auto mesh tool in PRO/Engineer Mechanica tool. The calculation model has 13680 solid tetra elements. PRO/Engineer uses linear approach to calculate the results and stress error percentage of the calculation model is 11.3 %. Results from balustrade calculations for solution 2 are presented in following figures.



Appendix 4 figure 8. Solution 2 – Balustrade load, Von Mises stress

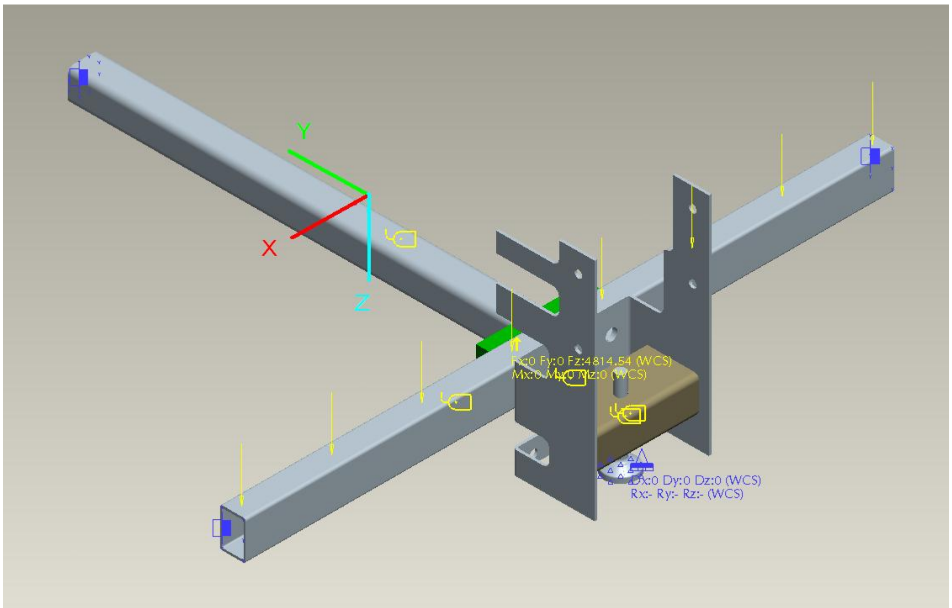


Appendix 4 figure 9. Solution 2 - Balustrade load, Displacements

SOLUTION 3

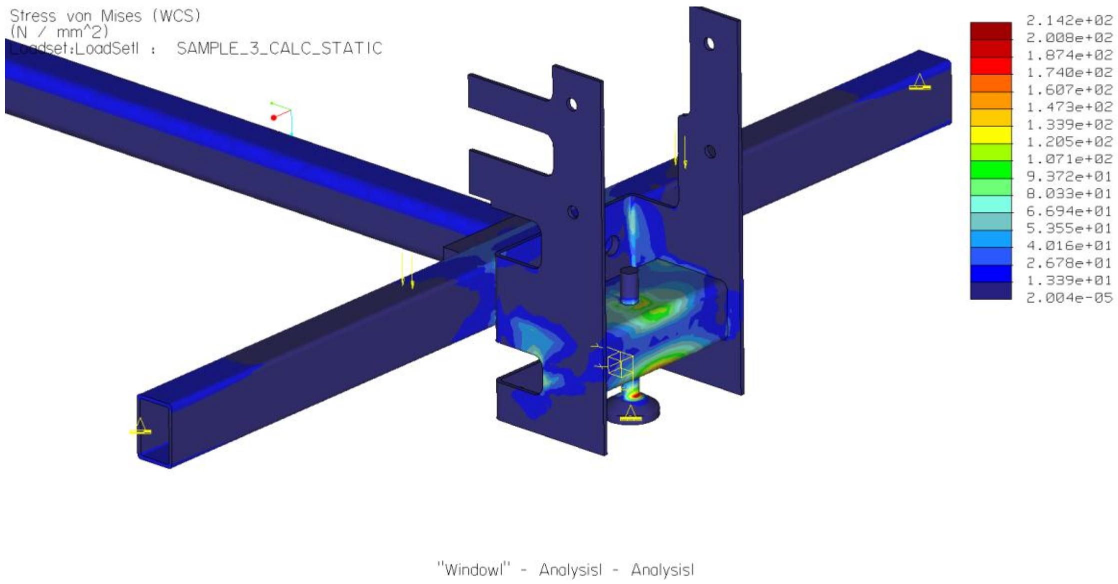
Rated load - Calculation model 4 and results

Calculation model 4 is to calculate stresses and displacements when rated load is applied. Calculation model uses symmetry and is one eight of the middle section. In the model there is one bracket and 1000 mm section from the roller track. Only upper roller track is modeled. Cross beam is half from the original length. There are together three mirror constraints one at the free end of the cross beam one in both ends of the roller track. Adjustable pad has a fully fixed constraint. Rated load is distributed on the upper surface of the roller track. Rated load is divided by eight because of the symmetry and its value is 4814.54N. Load is effecting in the direction of positive Z-axis. Each component is steel with Elastic modulus of 199948 MPa and Poisson ration 0.27. Calculation model is introduced in appendix 4 figure 10.

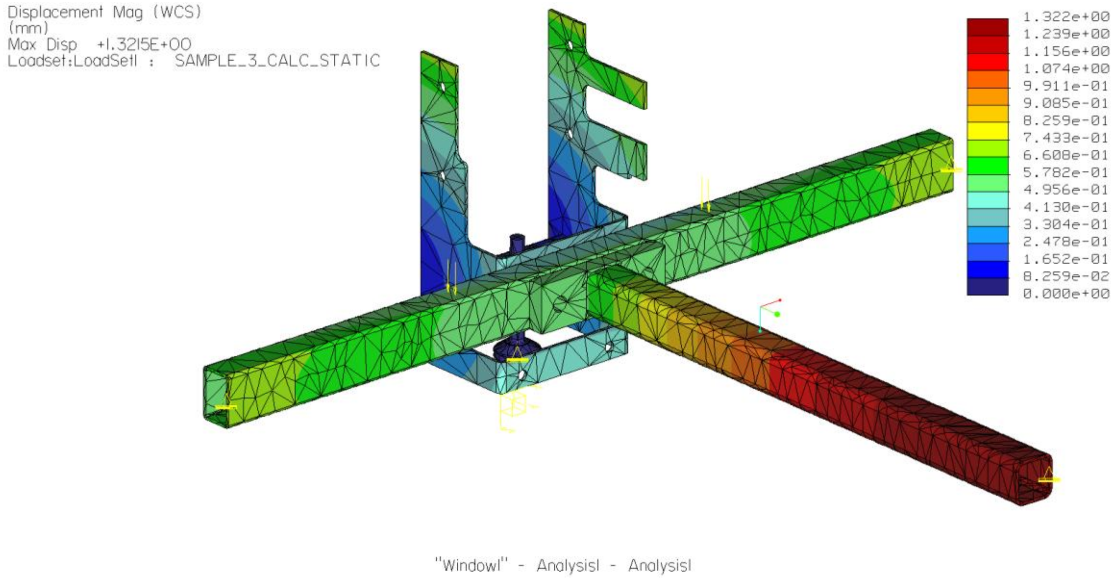


Appendix 4 figure 10. Rated load calculation model for solution 3

Meshing has done with auto mesh tool in PRO/Engineer Mechanica tool. The calculation model has 10644 solid tetra elements. PRO/Engineer uses linear approach to calculate the results and stress error percentage of the calculation model is 4.27 %. Results from rated load calculation for solution 3 are presented if following figures.



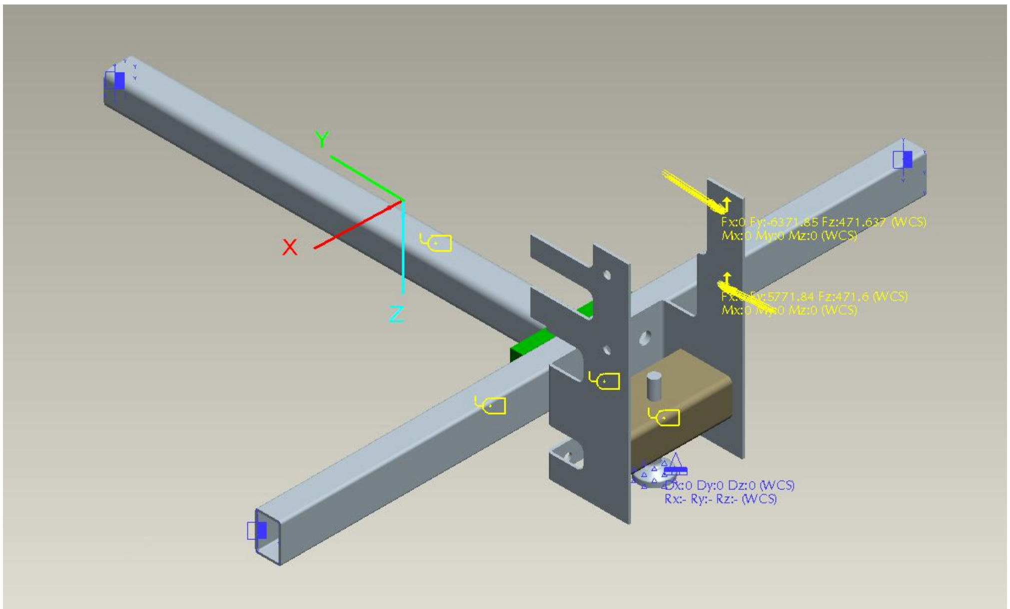
Appendix 4 figure 11. Von Mises stress calculation result for solution 3



Appendix 4 figure 12. Displacement calculation result for solution 3

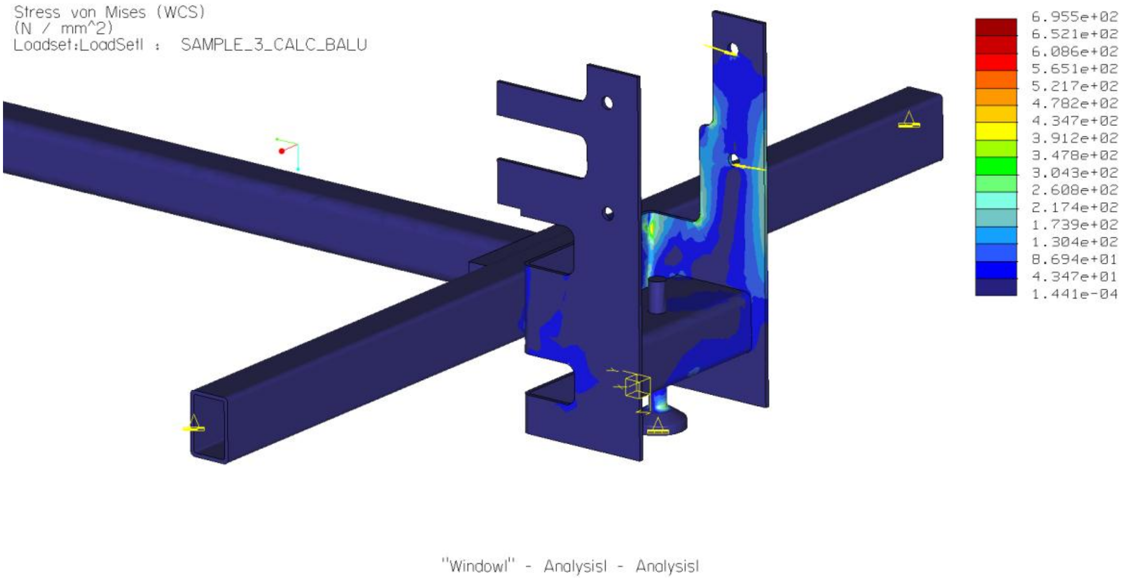
Balustrade load - Calculation model 5 and results

Calculation model 5 is to calculate stress and displacements when balustrade load is applied. Constraints and material properties in calculation model 5 are equal with the calculation model 4. Balustrade load is applied to the fixing holes of glass holder in supporting bracket. Reaction forces of the holes are calculated by using static equilibrium. Load on upper hole is -6371.84 N to the direction of Y-axis and 471.637N to direction of Z-axis. Load in lower hole is 5771.84 N to the direction of Y-axis and 471.637N to direction of Z-axis.

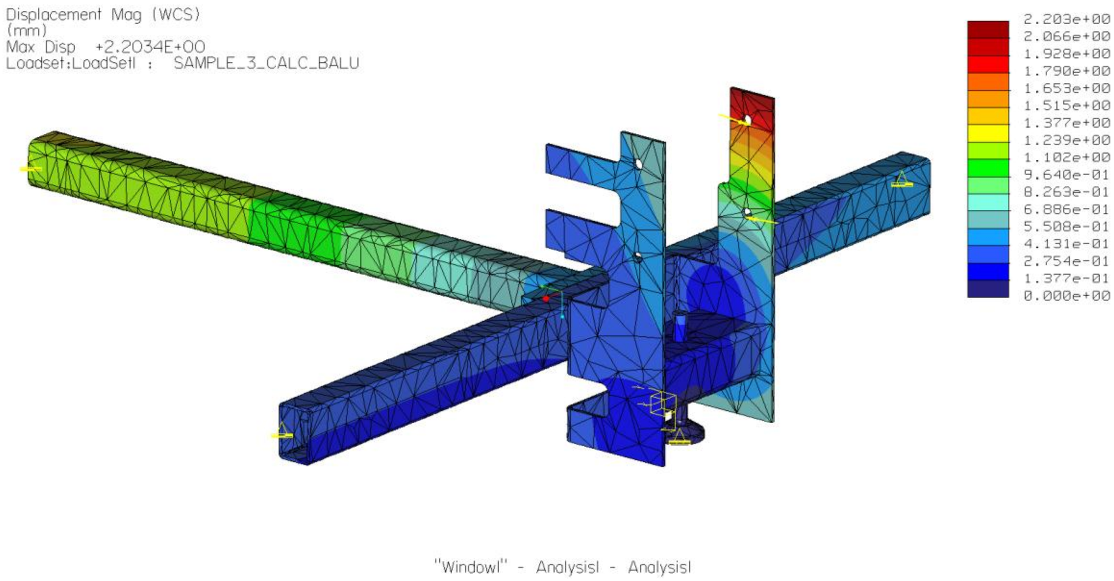


Appendix 4 figure 13. Balustrade load calculation model for solution 2

Meshing has done with auto mesh tool in PRO/Engineer Mechanica tool. The calculation model has 10161 solid tetra elements. PRO/Engineer uses linear approach to calculate the results and stress error percentage of the calculation model is 11.4 %. Results from balustrade load test for solution 3 are presented in following figures.



Appendix 4 figure 14. Solution 3 – Balustrade load, Von Mises stress



Appendix 4 figure 15. Solution 3 – Balustrade load, Displacement

Appendix 5. Advantages and disadvantages of created solutions

Supporting structure

The supporting structure for each solution is different. Solutions 2 and 3 are in principle the same but the implementation is different. Solution 1 is close to the original design. The similarity is good some areas as the original solution is well known and it is validated to work. However the most of the problems occurring in the original design are also occurring in solution 1. Solutions 2 and 3 are similar but the difference in roller track implementation is significant. Due to this reason the solution 3 is not in conflict with a patent no.: US 8,042,675 B2. The solution 2 however has some similarities with the patent claims. (Gonzalez, 2011)

The supporting structure of the solution 3 has the greatest advantages and the listed disadvantages are feasible to control. Like the original design the solutions 1 and 2 have big and heavy profiles as a supporting structure. These profiles are at the same time roller tracks and to achieve certain ride comfort level tolerances are required. Usually it is more challenging to control tolerances for big profiles than small ones.

Appendix 5 table 1: Supporting structure advantages and disadvantages

	Advantage	Disadvantage

Solution 1	- Smaller aluminum profile than original
	    - Less aluminum
	    - Better manufacturability
	    - Lighter profile
	- Original design is well known
	- Profile is not visual component
	    - No surface treatment
		- Same problems as original
		- No adjustment possibility
		    - Lot of preparations to the floor
		- Heavy extruding machine
		    - Strict tolerances

Solution 2	- Manufacturability
	  - Tolerances
	- Adjustable design
	- Simple design
	  - Modification possibilities
		- Need of roll form mould
		  - Big profile
		- Manufacturing method is for high volume
		- Screw connection carrying passenger load
		- Roll form profile conflicts with a patent no.: US 8,042,675 B2
		- Weight of the profile
		- Brackets are not fixed to anything

Solution 3	- Manufacturing method of each component is simple - Adjustable design - Simple design - Modification possibilities - Global availability - No truss	- Screw connection carrying passenger load - Supporting brackets are not fixed to anything

Roller Tracks

Roller track design is equal between solution 1 and the original design which means that it has the same problems and advantages as the original design. Solution 2 combines upper and lower track like the original design. As mentioned before the design has similarities as the US 8,042,675 B2 patent. For example this roll formed steel profile is claimed in the patent. The solution 3 is using separate standard hollow profiles as a roller tracks and they are fixed to the brackets. This approach is same with the conventional solution. According to the study the solution 3 has the best advantages. For solution 3 there are also disadvantages but the cost for controlling these is not as high as the one in other solutions. (Gonzalez, 2011)

Appendix 5 table 2: Roller track advantages and disadvantages.

	Advantage	Disadvantage
Solution 1	- Integrated to the truss - Simple design	- Squeaking noise - Need of the metal running plate - Same problems as original

Solution2	- Running tracks and guides are steel
	  - Ride comfort
	  - Durability
		- Need of roll form mould
		- Fixing of the guide
		- Roll form profile conflicts with a patent no.: US 8,042,675 B2

Solution 3	- Use of commercial pipe profiles
	- Closed profile on roller track
	  - Rigid
	- Simple design
	  - Modification possibilities
	- Global availability
		- Screw fixing to carry passenger load
		- Separate guiding nose profile
		- Hollow profile can't be compressed with high force

Balustrade

All solutions are using aluminum die cast glass holder to fix the balustrade glass. The principle is the same for all. The differences between these designs are in the way that the balustrade is fixed to the supporting structure. Solution 2 and 3 can be considered to be as good solutions. The displacement of the balustrade is expected to be larger than in original solution. The Solution 1 is considered to be the easiest to install in straight line as it is fixed to the aluminum profile and it can be designed so that it will align automatically.

Appendix 5 table 3: Balustrade advantages and disadvantages

	Advantage	Disadvantage
Solution 1	- Lining of the balustrade - Easy fixing of the glass holder - Use of the die cast glass holder	- Displacement of the balustrade
Solution 2	- Use of the die cast glass holder - Simple fixing	- Lining of the balustrade glass is highly depended on the bracket alignment - Rigidity of the fixing point - Displacement of the balustrade
Solution 3	- Use of the die cast glass holder - Simple fixing	- Lining of the balustrade glass is highly depended on the bracket alignment - Displacement of the balustrade

Handrail guiding system

Principle to implement the handrail guiding is same in all designs. Same advantages and disadvantages can be listed to all solutions.

Appendix 5 table 4: Handrail guiding system advantages and disadvantages

	Advantage	Disadvantage
Solution 1, 2 and 3	- Possibility to use standard components	- Handrail travel line needs to be lower than original - Bracket requires adjustments - Whole skirting needs to be removed when replacing handrail

Visual components

Visual appearance of each new solution is equal to each other. The shape is following the original design but the materials are different. Visual components such as skirting and cladding are all stainless steel. The fixing plates are carbon steel and basically follow same pattern in each solution. The differences are in the shapes fixing plates. Due to the similarity the advantages and disadvantages for these solutions are identical.

Appendix 5 table 5: Visual components advantages and disadvantages

	Advantage	Disadvantage

Solution 1, 2 and 3	- Skirting works same time as counter guide for passenger side pallet roller
	- Good accessibility to all components when skirting and inner decking are removed
	- Possibility to use desirable materials
		- Price of stainless steel
		- Aligning of the visual panels
		  - Complex fixing plates
		  - Lot of adjustments
		- Installation and removing is challenging
		- Whole skirting needs to be removed when replacing handrail

Module connection

Basic designs to connect middle section modules are simple for each solution. However to achieve the easiness the components must be manufactured with strict tolerances. Solution 1 has basically same principle as the original design. The design is easy to connect but the tolerance requirements are too strict for the big profile. It can be assumed that the solution 1 will have same issues for installation as the original. Solution 2 has also big profile and it will most likely have same challenges for manufacturing tolerances. Solution 3 has standard steel profiles as roller tracks the challenges is to control the connections between each needed component. Roller tracks need to be on right distance from each other and at the same time each track needs to be inside certain length tolerance.

Appendix 5 table 6: Module connection advantages and disadvantages

	Advantage	Disadvantage

Solution 1	- Easy to connect two modules
	- Running track plate on roller track makes sure of good ride comfort
	- Small changes to drive and tension head
		- Strict tolerance requirements
		  - Length
		  - Roller track heights

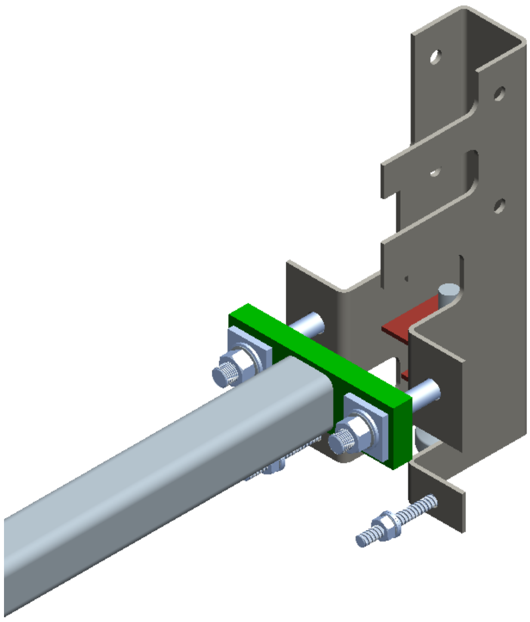
Solution 2	- Simple connection between two roll formed profiles	- Strict tolerance requirements
		  - Length
		  - Roller track heights
		- The interface of the roller track is in 90 degrees angle respect to the unit
		  - Ride comfort

Solution 3	- Simple connection between two middle sections modules
	  - 45 degree split in roller tracks
	  - Ride comfort
	- Connection to drive head is simple when head modules are modified
	- Tension head design to connect roller tracks
	  - Adjustability
		- Strict tolerances for roller track profiles
		- 4 separate interfaces to be connected

Appendix 6. Test samples

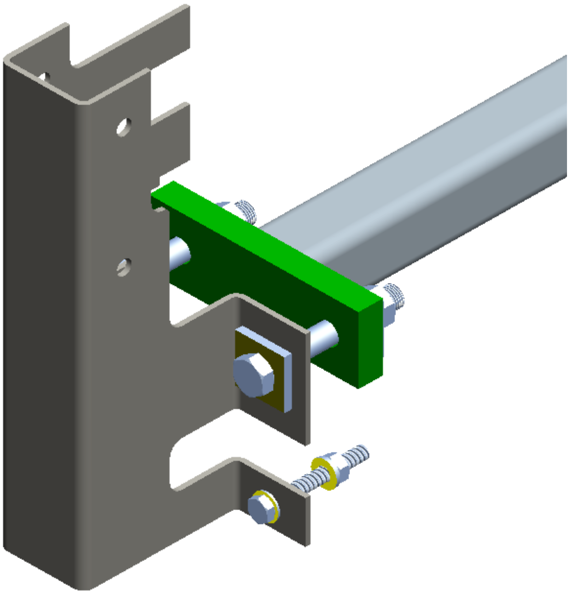
Three different bracket types are presented in following figures. All different brackets are manufactured by laser cutting from sheet metal plates and have same material thicknesses and materials.

The bracket type 1 is bended 4 times and the adjustable foot is located in side of the bracket. Bracket has one hole in each overhang, roller tracks and cross beam is fixed to these holes. Fixing is done with screw connection.



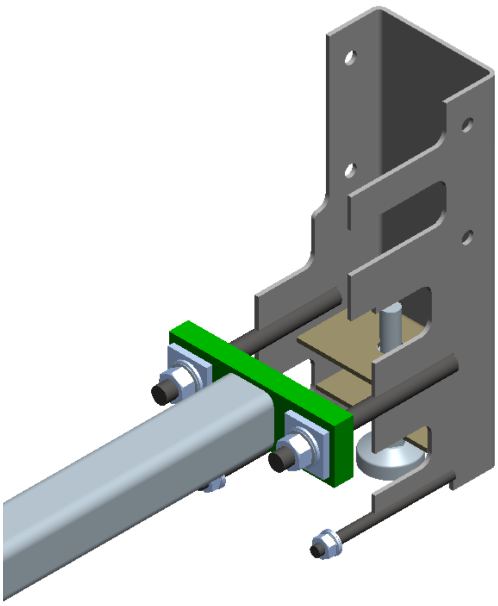
Appendix 6 figure 1. Bracket type 1

Bracket type 1 is open on the inside and the back of the bracket is continuous from bottom to top. This design is to make the balustrade fixing more rigid.



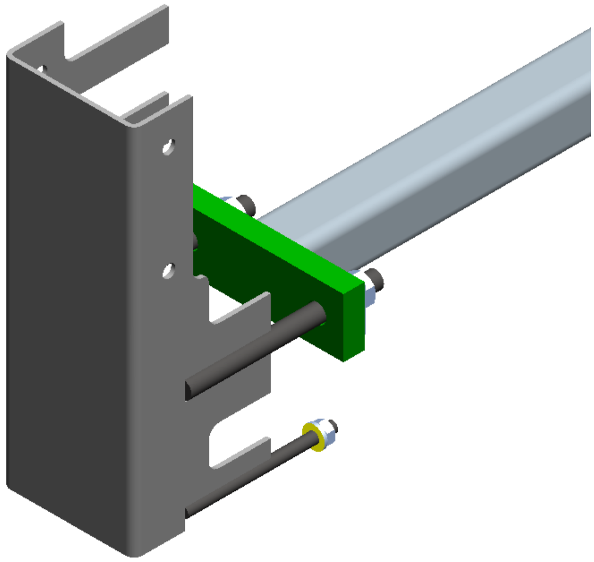
Appendix 6 figure 2. Bracket type 1

The bracket type 2 is bended 2 times and the adjustable foot is also located inside of the bracket. There are 4 screw bars welded to the bracket. Compared to the type 1 these bars enable the fixing only by using a nut and washers. Advantage is that number of components is reduced and fitter needs only one wrench to fix the nut.



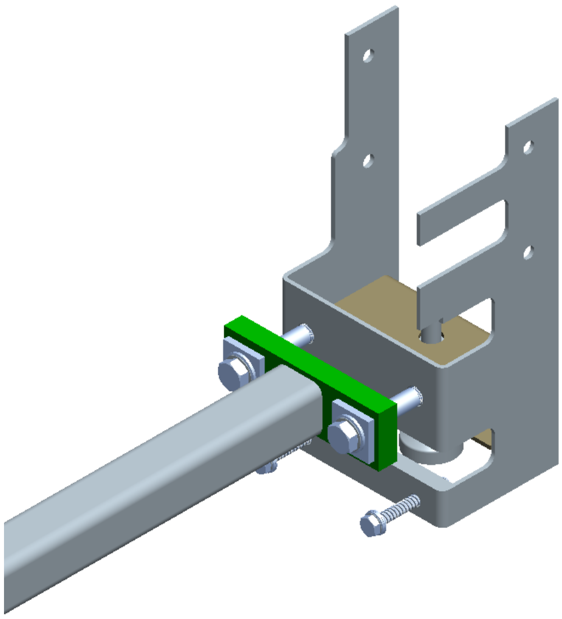
Appendix 6 figure 3. Bracket solution 2

Bracket type 2 is also open from the inside and the back of the bracket is closed from top to bottom. However the distance from left to right wall is longer than in bracket type 1



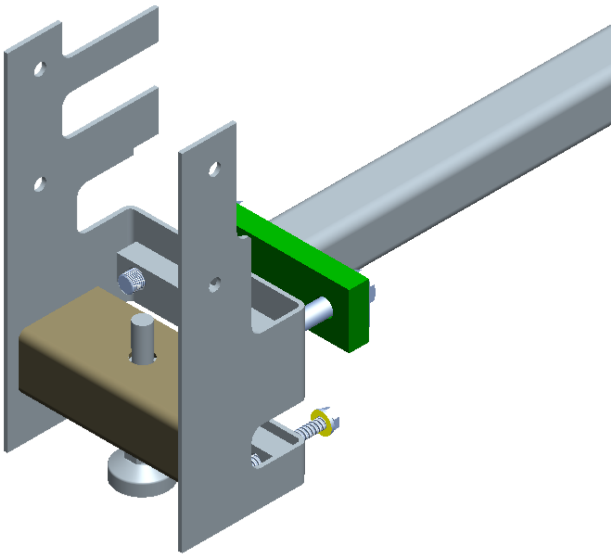
Appendix 6 figure 4. Bracket solution 2

Bracket type 3 is following the original design from creativity step. Bracket is bended 2 times and the adjustable foot is accessible from both sides of the bracket. The bracket has 4 holes in the front of the bracket to fix roller tracks. This bracket type uses also screws to fix the roller tracks and cross beam. However the screws are fixed to a threaded block instead of nut. With this solution the fitter can use only one wrench to fix the screw.



Appendix 6 figure 5. Bracket solution 3

The bracket is bended so that it is open from the back and the fixing interface is the base wall. Balustrade glass holder is designed to be fixed on to the other bended wall of the bracket.

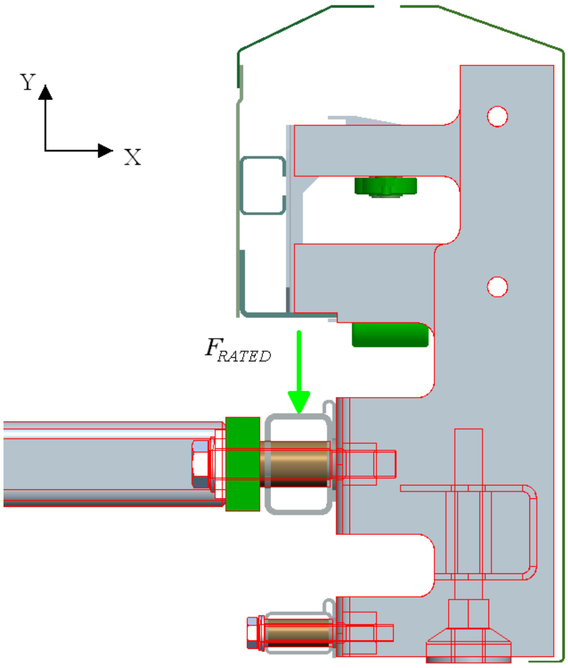


Appendix 6 figure 6. Bracket solution 3

Appendix 7. Screw fixing calculations R2.0

Given values:

F_{RATED}	4814.54 N	Static load
n_{bolts}	2	number of bolts
d_x	20 mm	distance from load, x-direction
d_y	30 mm	distance from load, y-direction
μ	0.15	Friction factor (*lubrication*)
F_{Rt}	72.5 – 81 kN	Axial tensile strength M16 8.8 bolt



Appendix 7 figure 1. Load location for screw fixing calculation

Friction load:

$$F_{\mu} = N_I \cdot n_{bolts} \cdot \mu$$

N_i is the normal force

$$N_i = \frac{F_{RATED}}{n_{bolts} \cdot \mu}$$

Tightening force calculations:

$$Q_i = Q_R + Q_e$$

Q_r is needed tightening force static case and Q_e is needed tightening force in dynamic case

$$Q_R = N_I$$

$$Q_e = \frac{\frac{F_{RATED}}{n_{bolt}} \cdot d_x}{d_y}$$

Safety factor:

$$SF = \frac{F_{Rt}}{Q_i}$$

Pre tightening force:

$$Q_{0\_1} = Q_R + Q_e \cdot \left(1 - \frac{k_b}{k_b + k_c}\right)$$

k_b is constant factor depending on the used washer type and k_c is constant factor depending on the used washer type

$$\left(1 - \frac{k_b}{k_b + k_c}\right) = 1 - 0.2 = 0.8$$

Calculations:

$$N_i = \frac{F_{RATED}}{n_{bolts} \cdot \mu} = \frac{4814.54N}{2 \cdot 0.15} = 16048.47N$$

$$Q_R = N_I$$

$$Q_e = \frac{\frac{F_{RATED}}{n_{bolt}} \cdot d_x}{d_y} = \frac{\frac{4814.54}{2} \cdot 20mm}{30mm} = 1604.85N$$

$$Q_i = Q_R + Q_e = 16048.47N + 1604.85 = 17653.31N$$

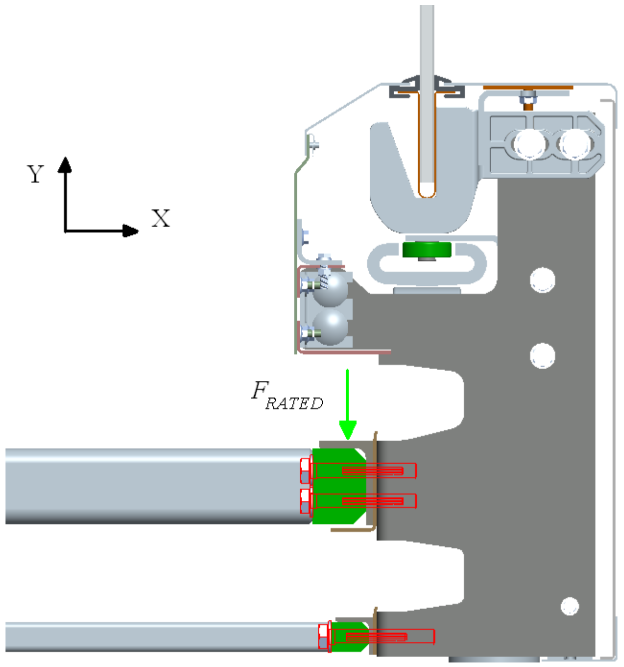
$$SF = \frac{F_{Rt}}{Q_i} = \frac{72500N}{176353.31N} = 4.11$$

$$Q_{0\_1} = Q_R + Q_e \cdot \left(1 - \frac{k_b}{k_b + k_c}\right) = 16048.47N + 1604.85N \cdot 0.2 = 16369.44N$$

Appendix 8. Screw fixing calculations R2.5

Given values:

F_{RATED}	4814.54 N	Static load
n_{bolts}	4	number of bolts
d_x	10 mm	distance from load, x-direction
d_{y1}	20 mm	distance from load, y-direction
d_{y2}	40 mm	distance from load, y-direction
μ	0.15	Friction factor (*lubrication*)
F_{Rt}	26.3 – 29.4 kN	Axial tensile strength M10 8.8 bolt



Appendix 8 figure 1. Load location for screw fixing calculation

Equations according to formulas in appendix 7.

Caluclations:

$$N_i = \frac{F_{RATED}}{n_{bolts} \cdot \mu} = \frac{4814.54N}{4 \cdot 0.15} = 8024.23N$$

$$Q_R = N_I$$

$$Q_e = \frac{\frac{F_{RATED}}{n_{bolt}} \cdot d_x}{d_{y1}} + \frac{\frac{F_{RATED}}{n_{bolt}} \cdot d_x}{d_{y2}} = \frac{\frac{4814.54}{4} \cdot 10mm}{20mm} + \frac{\frac{4814.54}{4} \cdot 10mm}{40mm} = 902.72N$$

$$Q_i = Q_R + Q_e = 8024.23N + 902.72N = 8926.95N$$

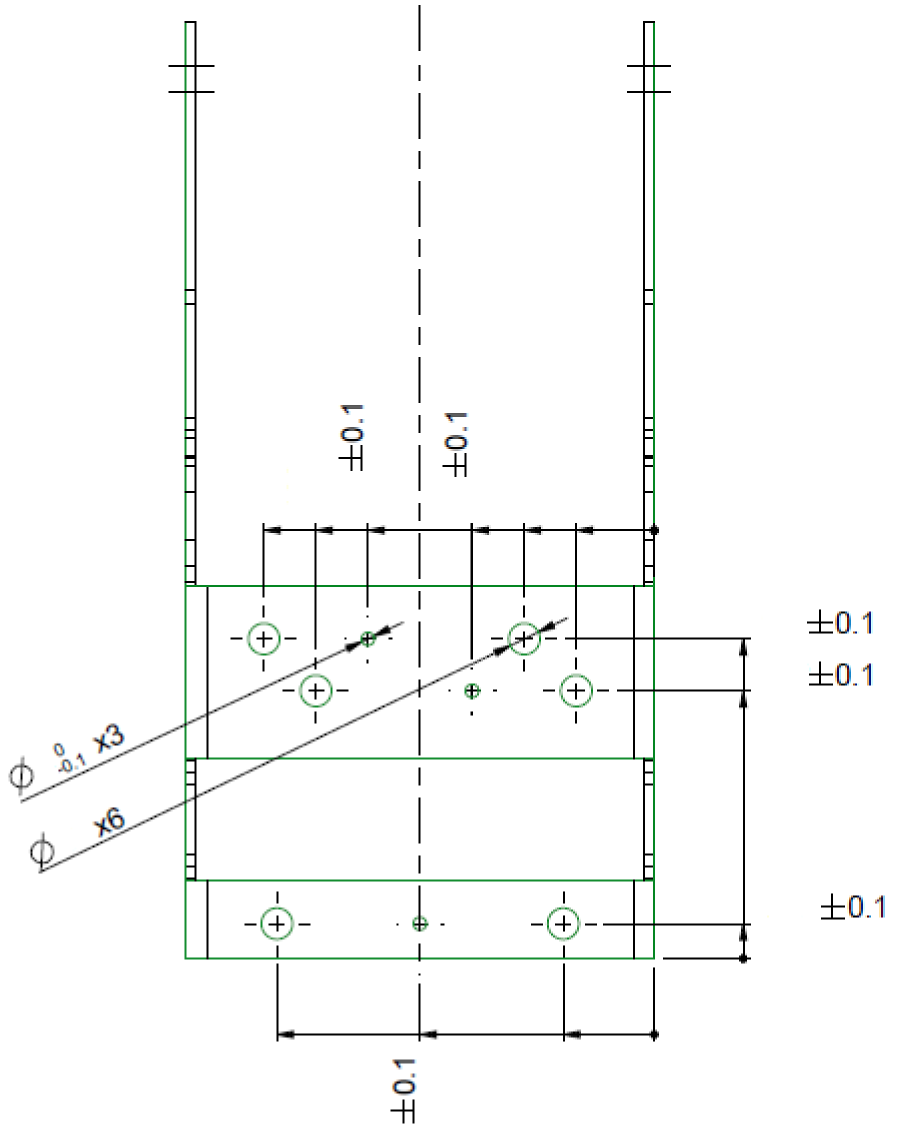
$$SF = \frac{F_{Rt}}{Q_i} = \frac{26300N}{8926.95N} = 2.95$$

$$Q_{0\_1} = Q_R + Q_e \cdot \left(1 - \frac{k_b}{k_b + k_c}\right) = 8024.23N + 902.72N \cdot 0.2 = 8204.77N$$

Appendix 9. Tolerance review for R2.5 design

SELF-SUPPORTING BRACKET

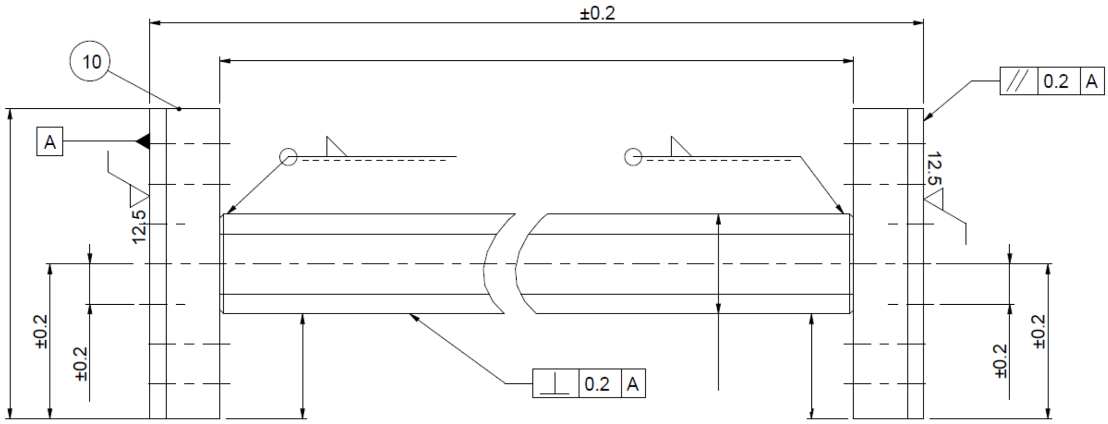
Manufacturing tolerances for holes in self-supporting bracket are presented in appendix 9 figure 1appendix 9 figure 1.



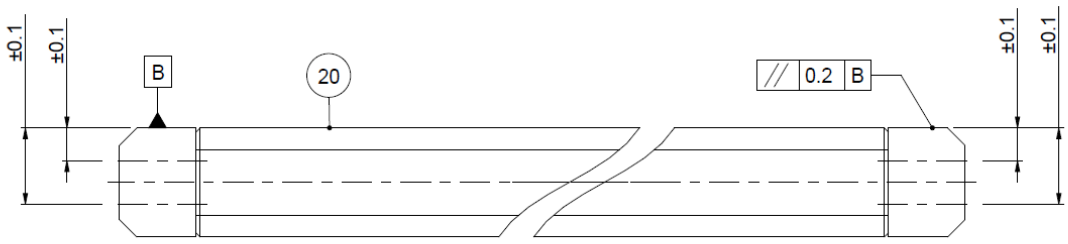
Appendix 9 figure 1. Manufacturing tolerances for bracket

CROSS BEAM

Manufacturing tolerances for upper cross beam are presented in appendix 9 figure 2 and appendix 9 figure 3.



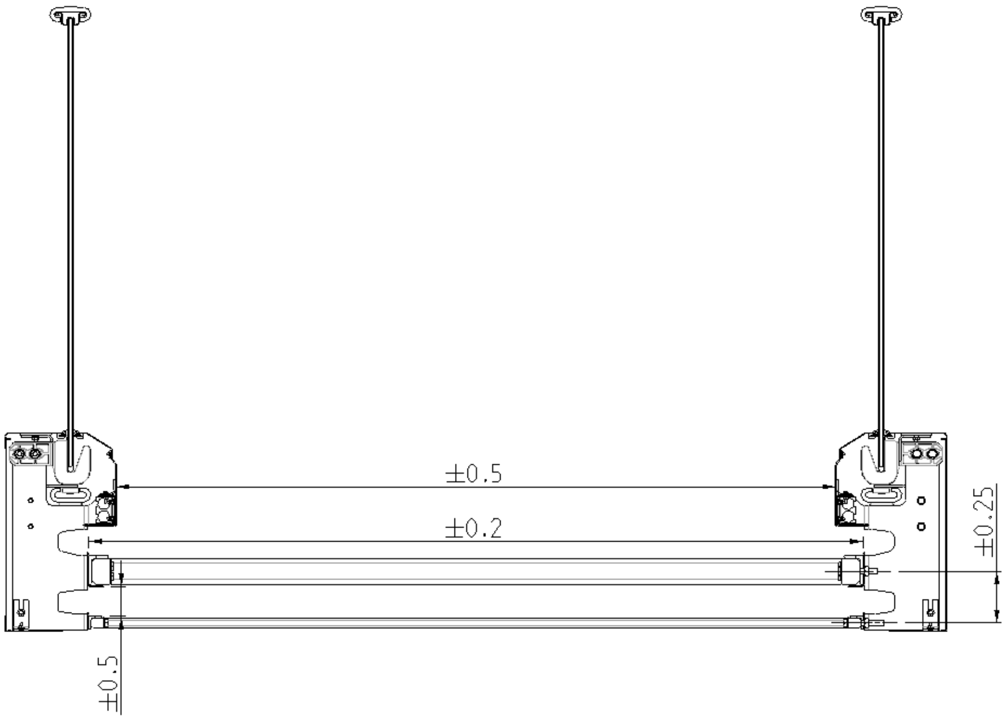
Appendix 9 figure 2. Manufacturing tolerances for upper cross beam



Appendix 9 figure 3. Manufacturing tolerances for upper cross beam

TOLERANCES FOR ASSEMBLY

Key tolerances for the unit are presented in appendix 9 figure 4. The tolerances are calculated according to the presented component tolerances. Due to the cross beam tolerances the roller tracks are always ± 0.2 mm from each other. Height between the roller tracks is always ± 0.25 mm. More important dimension is the distance between the lower roller track and counter guide which is always ± 0.5 mm. When skirting panels are compressed against brackets the distance between them is always ± 0.5 mm.



Appendix 9 figure 4. Key tolerances for the unit

Appendix 10. Supporting structure test

PURPOSE OF THE TEST

Target is to verify the mechanical strength of supporting structure according to EN 115-1, clause 5.2.5

ACCEPTANCE CRITERIA

5.2.5 Structural design

The supporting structure shall be designed in a way that it can support the dead weight of the escalator or moving walk plus a rated load of 5000 N/m2. It shall be calculated in accordance with EN 1993-1-1.

NOTE Load carrying area = (nominal width z_1 (see Figure 3) of the escalator or moving walk) x (distance l_1 between the supports)

Based on the rated load, the maximum calculated or measured deflection shall not exceed 1/750 of the distance l_1 between the supports.

DESCRIPTION OF THE TEST SYSTEM

There are three different prototypes for this test. Each of them has different supporting brackets and they will be tested in two load cases.

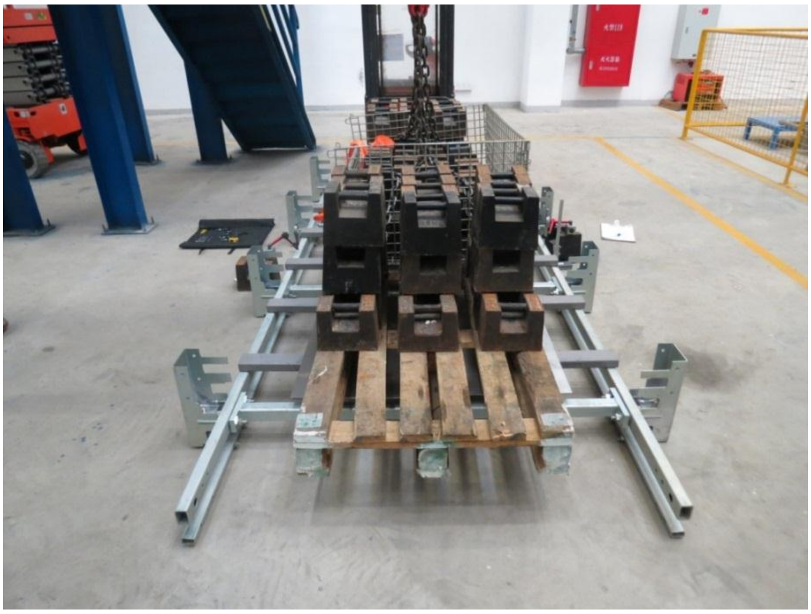
Load case 1 is to measure displacement of the cross beam when rated load is applied. Test system for load case 1 is presented in appendix 10 figure 1. Test system is 2000 mm long and it has 6 supporting brackets and 3 cross beams. All roller tracks are 4000 mm long.

Rectangular hollow profiles and sheet metal plates are placed on top of the upper roller tracks. The load is applied with 25 kg weights that are lifted on top of the hollow profiles.

Appendix 10 figure 1. Test system for load case 1

Load case 2 is to measure displacement if the roller tracks when rated load is applied. Test system for load case 2 is presented in appendix 10 figure 2. Test system is 3000 mm long and has 8 supporting brackets and 4 cross beams. All roller tracks are 4000 mm.

Rectangular hollow profiles and sheet metal plates are placed on top of the upper roller tracks. The load is applied with 25 kg weights that are lifted on top of the hollow profiles.



Appendix 10 figure 2. Test system for load case 2

Measurement System Analysis

Load in both cases is applied by using 25 kgweights. These weights are on wooden pallets and inside of a metal basket. The weight of the basket and pallets is unknown. Due to this reason used weight in each test is bigger than calculated rated load. The weights are put on top of the roller tracks by using electric fork lift. This means that the positions of the weights are varying and it effects to the results. The weight is higher than calculated rated load and therefore the results can be considered to be trust worthy even though the load is not equally distributed to roller tracks.

Design for roller tracks is different between the test systems. Roller tracks for test system with bracket type 1 and 2 have inserted bushings inside of the hollow roller track profile. These bushings are not fixed to the profile. In test system with bracket type 3 the bushings are welded to the hollow profile.

Purchased samples are not according to the manufacturing drawings most of them are not meeting the required tolerances. However the components are accurate enough for these tests.

SAMPLES NEEDED

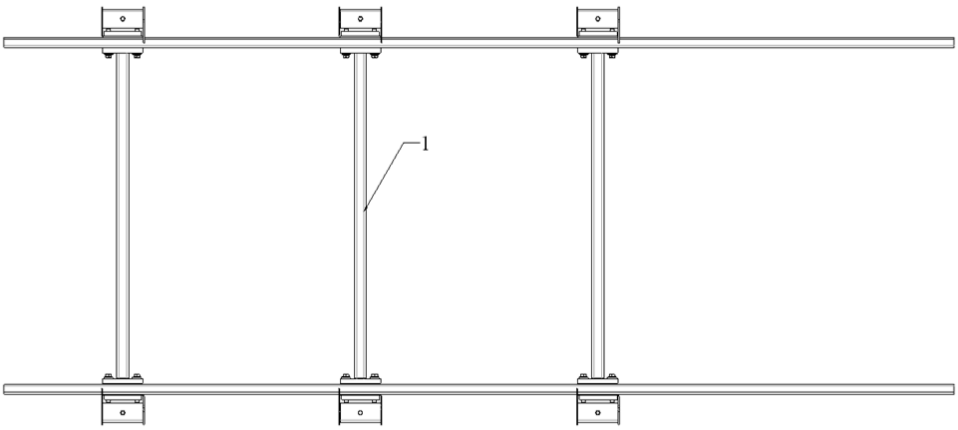
Appendix 10 table 1: Samples needed

Prototype	Middle section module, bracket type 1	Middle section module, bracket type 2	Middle section module, bracket type 3
Nominal width	1400 mm	1400 mm	1400 mm
Length	4000 mm	4000 mm	4000 mm
Incline angle	0 degree	0 degree	0 degree

TEST PLAN

Load case 1

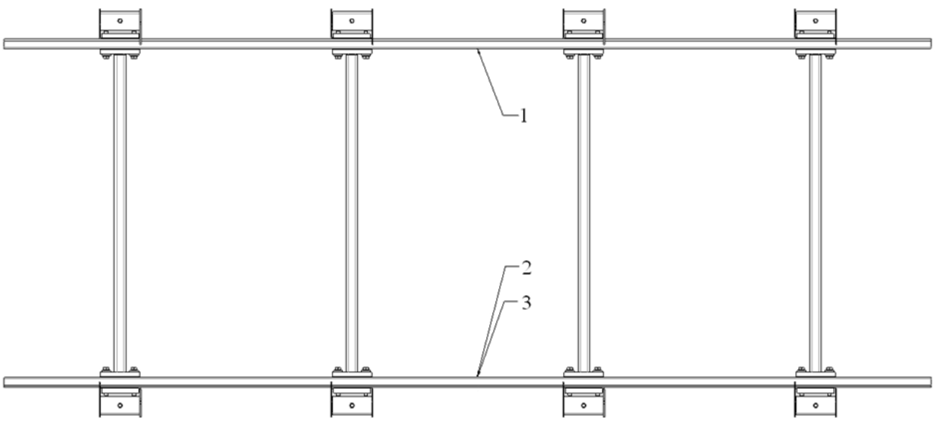
1) Install 2 meter section and place the hollow profiles on top of the roller tracks
2) Place the dial indicator according to the appendix 10 figure 3.
3) Apply rated load according to the clause 5.2.5
4) Read the deflection of the cross beam from the dial indicator and record it
5) Release the load and record the value from the dial indicator



Appendix 10 figure 3. Test system for load case 1

Load case 2

1) Install 3 meter section and place the hollow profiles on top of the roller tracks
2) Place the dial indicators according to the appendix 10 figure 4.
3) Steps 3-5 according to load case 1



Appendix 10 figure 4. Test system for load case 2

TEST RESULTS

Load case 1

Results from load case 1 are presented in appendix 10 table 1. Positive deflection value indicates movement towards the floor. Maximum deflection is calculated in equation 1.

$$d_1 = \frac{l_1}{750} = \frac{1655mm}{750} = 2.21mm \tag{1}$$

Appendix 10 table 2: Load case 1 - Cross beam displacement under rated load

Test	Deflection under load [mm]	Deformation after load released [mm]
Bracket type 1		
1	1.70	0.18
2	1.39	0.03
Bracket type 2		
3	1.86	0.21
4	1.47	0.05
Bracket type 3		
5	1.89	0.07
6	1.81	0.01

Weight on upper roller tracks before test: 110 kg. Weight on upper roller tracks during the test: 1950 kg+ 2 wooden pallets + 110 kg= 2120 kg (estimation). Estimated weight for one wooden pallet: 30kg

Load case 2

Results from load case 2 are presented in

. Positive deflection value indicates movement towards the floor. Maximum deflection is calculated in equation 2.

$$d_1 = \frac{l_1}{750} = \frac{1000mm}{750} = 1.33mm \tag{2}$$

Appendix 10 table 3: Load case 2 - Roller track displacements under rated load

Measuring position	Deflection under load [mm]	Deformation after load released [mm]
Bracket type 1		
Upper roller track - left	1.00	0.08
Upper roller track - right	0.74	0.04
Lower roller track - right	0.58	0.02
Bracket type 2		
Upper roller track - left	0.71	0.19
Upper roller track - right	0.78	0.14
Lower roller track - right	0.46	0.08
Bracket type 3		
Upper roller track - left	1.07	0.11
Upper roller track - right	1.03	0.12
Lower roller track - right	0.56	0.06

Weight on upper roller tracks before test: 142 kg. Weight on upper roller tracks during the test: 2875 kg+ 2 wooden pallets + metal basket + 142 kg= 3127 kg(estimation). Estimated weight for one wooden pallet: 30 kg. Estimated weight for one metal basket: 50kg

CONCLUSION

1) For test according to the clause 5.2.5, for each prototype the displacements between support points were less than L/750
2) No permanent deformations
    - Measured values after load taken away are small
    - It is likely that the used way to put load on top of the roller tracks caused movement on the system which can be seen as deviation from zero value.
    - The spherical joint on adjustable foot has slack and is to believe to move during the test

LESSONS LEARNED

Every bracket type passed the test. The displacement results are relatively close to each other. Biggest differences between brackets are not in capability to carry rated load.

The weights on second load case were applied in a way that metal basket was put first on the roller tracks and the wooden pallets after. During this test it was noticed that the deflection vales are higher when the basket is on top of the tracks and the values were decreased after the two wooden pallets were put on to the tracks. The behavior was studied and concluded that: when load is applied between two support points the free ends of the roller track aims to move upwards. The structure is not heavy enough to prevent this movement. In normal use of moving walk this is not likely to happen as the passenger load is 41 % from rated load.

Bracket type 1 was calculated to be the strongest from the three different samples. However according to the test results the bracket type 2 has the smallest deflections. Decision for the best solution is to be done according to the installation study and balustrade strength test. During the tests the structure was assembled and dismantled several times. From installations view of point the bracket type 3 is most suitable. Best advantage against other three is the access to adjust the foot height. Also the bracket type 3 was found to meet the required tolerances.

Bracket type 3 has fixing holes on a same base wall which means that the distance between these holes is easy to keep inside of the tolerance requirement.

DEVELOPMENT ACTIONS

Fixing plate design for the foot is to be redesigned. Welding of this fixing plate should be easier and by changing the design it can be more rigid.

Appendix 11. Balustrade strength test R2.0

PURPOSE OF THE TEST

Target is to verify the mechanical strength of the balustrade according to EN 115-1.

Clause: 5.5.2.3

ACCEPTANCE CRITERIA

EN 115-1

5.5.2.3 Balustrades shall be designed to resist the simultaneous application of a static lateral force of 600 N and a vertical force of 730 N, both equally distributed over a length of 1 m and acting on the top of the handrail guiding system in the same place.

Description of the Test System

For test according to clause 5.5.2.3, test was done with InnoTrack™ preliminary prototype. The static lateral and vertical force are applied by screw bars. Each screw bar is fixed with a force sensor to measure the force. The force act on the top of handrail guiding system through a 1 m C profile steel. Test systems for both bracket types are presented in appendix 11 figure 1 and appendix 11 figure 2.

Appendix 11 figure 1. Test system for bracket type 1

Appendix 11 figure 2. Test system for bracket type 3

Measurement System Analysis

The load to the balustrade is applied with screw bars. These screw bars are fixed to aluminum frame which is fixed to an electric fork lift. During the test the aluminum frame deflects because of the reaction force from screw bars. This is effecting slightly to the angle that the force is applied to the structure. Also for the same reason it is difficult to apply load so that it increases evenly. Once the right load is reached the system is able to keep the load relatively stable.

The balustrade glass is fixed with die cast aluminum glass holders. The KONE material number for this is KM5259568G01. This glass holder is not standard model as part of the holder is cut. The holder is fixed to the bracket with fixing plate in both test systems. It can be assumed that the holder is strong enough and has only minimal effect to the deflection of the balustrade. However this design is not going to be the final design to fix the balustrade.

The test system covers only load carrying structure. There is no skirting or inner decking to support the balustrade panel. Dead weight of the tested structure is lower than final solution. The dead weight of the pallets is simulated by applying weights on the upper roller track.

Design for roller tracks is different between the two test systems. Roller tracks for test system with bracket type 1 have inserted bushings inside of the hollow roller track profile. These bushings are not fixed to the profile. In test system with bracket type 3 the bushings are welded to the hollow profile. Based on the previous supporting load test I can be assumed that the design of the roller track won't have notable effect to the test results.

Purchased samples are not according to the manufacturing drawings most of them are not meeting the required tolerances. However the components are accurate enough for these tests.

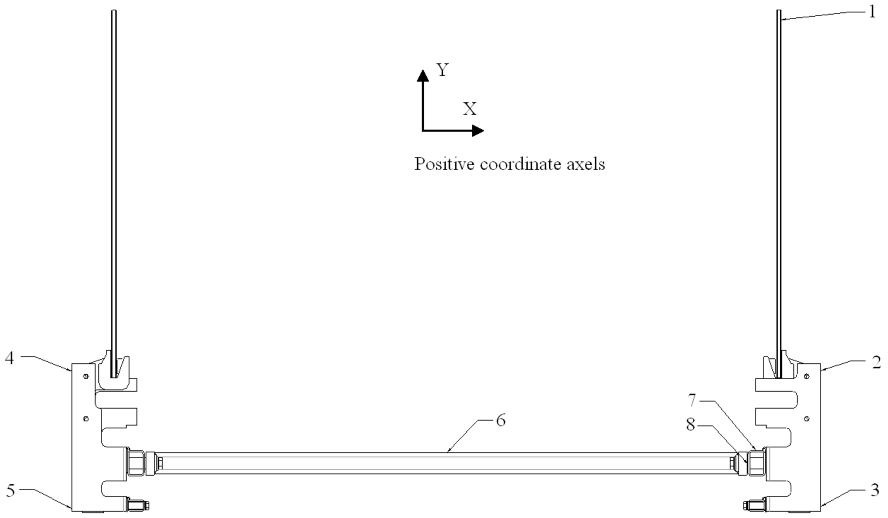
SAMPLES NEEDED

Appendix 11 table 1: Samples needed

Prototype	Middle section module, bracket type 1 R2.0	Middle section module, bracket type 3 R2.0
Manufacture No.	-	-
Nominal width	1400 mm	1400 mm
Height of balustrade	Nominal: 1000 mm Glass: 863 mm	Nominal: 1000 mm Glass: 863 mm
Rise	0 mm	0 mm
Length	Prototype 4000 mm Balustrade 3000 mm	Prototype 4000 mm Balustrade 3000 mm
Incline angle	0 degree	0 degree
Speed	-	-
Level step quantity	-	-
Motor power	-	-

TEST PLAN

1) Mark test points according to the appendix 11 figure 3**Error! Reference source not found.**.
2) Place 8 dial indicators to the marked positions.appendix 11 figure 3.
    a. On top of the balustrade (horizontal movement)
    b. Back of the right side bracket, upper edge (horizontal movement)
    c. Back of the right side bracket, lower edge (horizontal movement)
    d. Back of the left side bracket, upper edge (horizontal movement)
    e. Back of the left side bracket, lower edge (horizontal movement)
    f. Middle of the cross beam (vertical movement)
    g. On top of the roller track (vertical movement)
    h. On the side of the roller track (horizontal movement)
3) Apply balustrade load according to the clause 5.5.2.3, 600 N in vertical direction and 730 N in horizontal direction.
4) Read the deflections from the dial indicators and record it.
5) Release the force and record the permanent deformation.
6) Perform steps 3, 4 and 5 two times.



Appendix 11 figure 3. Positions for dial indicators and positive coordinate axels

TEST RESULTS

Bracket type 1

Test results for bracket type 3 are presented in following tables.

Appendix 11 table 2: Bracket type 1 R2.0, 1st test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	31.54	31.5	1.25	1.07
2	1.92	1.92	0.13	0.13
3	-0.08	-0.08	-0.01	-0.01
4	0.97	0.95	-0.01	0.01
5	0.29	0.29	0.08	0.08
6	0.29	0.29	0.08	0.08
7	0.51	0.51	0.06	0.06
8	0.51	0.51	0.05	0.05

Appendix 11 table 3: Bracket type 1 R2.0, 2nd test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	31.65	31.63	1.71	1.61
2	1.84	1.84	0.15	0.15
3	-0.1	-0.1	-0.01	-0.01
4	0.97	0.97	0.04	0.04
5	0.23	0.23	0.06	0.06
6	0.28	0.28	0.06	0.06
7	0.48	0.48	0.05	0.05
8	0.49	0.48	0.06	0.06

Bracket type 3

Test results for bracket type 3 are presented in following tables.

Appendix 11 table 4: Bracket type 3 R2.0, 1st test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	27.47	27.43	0.12	0.05
2	1.69	1.72	0.03	0.01
3	-0.12	-0.12	-0.01	0.00
4	0.45	0.46	0.00	0.01
5	0.31	0.32	0.01	0.01
6	0.46	0.48	0.03	0.02
7	0.31	0.33	0.01	0.00
8	0.36	0.38	0.01	0.00

Appendix 11 table 5: Bracket type 3 R2.0, 2nd test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	25.13	25.10	0.07	0.01
2	1.53	1.53	0.01	0.00
3	-0.11	-0.12	0.00	0.00
4	0.43	0.43	0.01	0.01
5	0.28	0.28	0.00	0.00
6	0.41	0.41	0.01	0.01
7	0.29	0.29	0.00	0.00
8	0.33	0.33	0.00	0.00

CONCLUSION

Bracket type 1

1) The glass panel was not broke or damaged during and after the test
2) For test according to clause 5.5.2.3, the balustrade was not broke or damaged during and after the test.
3) The permanent deformation for bracket type 1 was 1.7 mm.
4) Highest deflection value for balustrade is not in acceptable level
5) The supporting structure works as a system in unwanted way
    a. Left and right side are linked together and load causes deflections in both sides.
    b. Roller track deflects under balustrade load

Bracket type 3

1) The glass panel was not broke or damaged during and after the test
2) For test according to clause 5.5.2.3, the balustrade was not broke or damaged during and after the test.
3) There were no permanent deformations for bracket type 3.
4) Highest deflection value for balustrade is not in acceptable level
5) The supporting structure works as a system in unwanted way
    a. Left and right side are linked together and load causes deflections in both sides.
    b. Roller track deflects under balustrade load

LESSONS LEARNED

Each function of the middle section is linked to the brackets. Components are strong enough to carry the load. The deflections on the system cause unwanted behavior for the structure.

The bracket is not fixed to the floor and can rotate around the supporting foot. Components and fixings are not rigid enough to stop the bracket to move around the foot. The bracket movement around the foot needs to be locked.

DEVELOPMENT ACTIONS

Design a lower cross beam and link left and right side brackets from secondary point. Execute the balustrade load test again. If the unwanted behavior continues prevent the bracket to move by using wedges.

Appendix 12. Balustrade strength test R2.1

PURPOSE OF THE TEST

Target is to verify the mechanical strength of the balustrade according to EN 115-1.

Clause: 5.5.2.3

5.5.2.4

ACCEPTANCE CRITERIA

EN 115-1

5.5.2.3 Balustrades shall be designed to resist the simultaneous application of a static lateral force of 600 N and a vertical force of 730 N, both equally distributed over a length of 1 m and acting on the top of the handrail guiding system in the same place.

5.5.2.4 The parts of the balustrade facing the steps, pallets or belt shall be smooth and flush. Covers not in the direction of travel shall not project more than 3 mm. They shall be rigid and have rounded or beveled edges. Covers of such nature are not permitted at the skirting. Cover joints in the direction of travel (in particular between the skirting and the interior panel) shall be arranged and formed in such a manner as to eliminate any risk of harm caused by trapping. Gaps between the interior panels of the balustrade shall be not wider than 4 mm. The edges shall be rounded off or beveled. When a force of 500 N is applied to the interior panel at any point of the paneling at right angles on an area of 25 cm2, there shall be no gap greater than 4 mm and no permanent deformation. Where mechanical testing is required in accordance with this standard, setting tolerances are permitted 5251836D50:

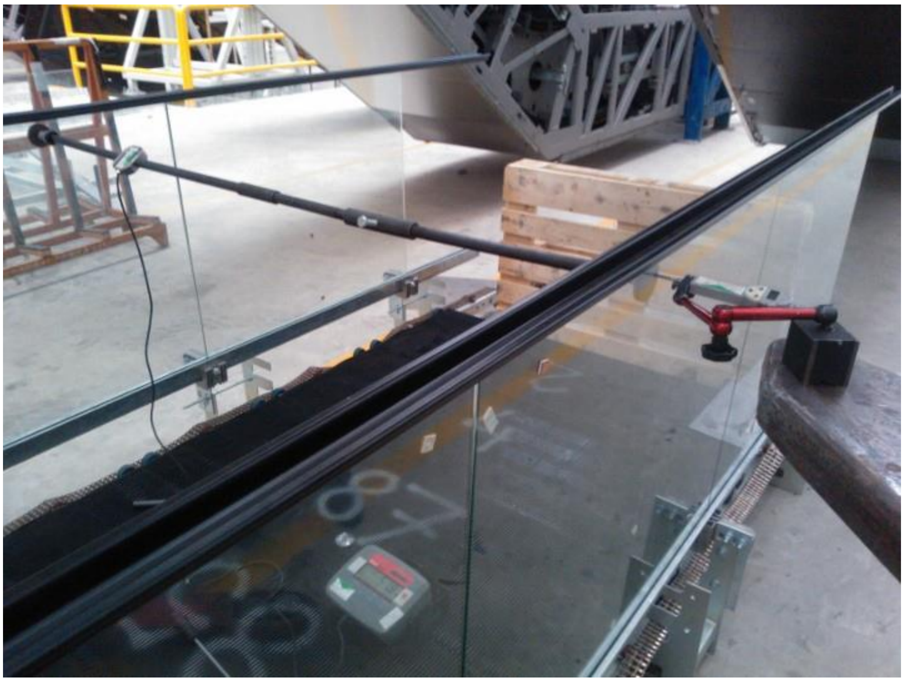
When a force of 500 N is applied to the interior panel at any point of the panel at right angles on an area of 25 cm2, there shall be no gap greater than 4 mm and permanent deformation is less than 0.8 mm.

DESCRIPTION OF THE TEST SYSTEM

For test according to clause 5.5.2.3, test was done with InnoTrack™ preliminary prototype. The static lateral and vertical force are applied by screw bars. Each screw bar is fixed with a force sensor to measure the force. The force act on the top of handrail guiding system through a 1 m C profile steel. Test system for bracket type 3 is presented in appendix 12 figure 1.

Appendix 12 figure 1. Test system for bracket type 3

For test according to clause 5.5.2.4, test was done with InnoTrack™ preliminary prototype. A force of 500 N is applied to the chosen glass panel at test point at right angles on an area of 25 cm² through force sensor and measuring amplifier. Test system is presented in appendix 12 figure 2.


Appendix 12 figure 2. Test system according to clause 5.5.2.4

Measurement System Analysis

The load to the balustrade is applied with screw bars. These screw bars are fixed to aluminum frame which is fixed to an electric fork lift. During the test the aluminum frame deflects because of the reaction force from screw bars. This is effecting slightly to the angle that the force is applied to the structure. Also for the same reason it is difficult to apply load so that it increases evenly. Once the right load is reached the system is able to keep the load relatively stable.

The balustrade glass is fixed with die cast aluminum glass holders. The KONE material number for this is KM5259568G01. This glass holder is not standard model as part of the holder is cut. The holder is fixed to the bracket with fixing plate in both test systems. It can be assumed that the holder is strong enough and has only minimal effect to the deflection of the balustrade. However this design is not going to be the final design to fix the balustrade.

The test system covers only load carrying structure. There is no skirting or inner decking to support the balustrade panel. Dead weight of the tested structure is lower than final solution. The dead weight of the pallets is simulated by applying weights on the upper roller track.

Purchased samples are not according to the manufacturing drawings most of them are not meeting the required tolerances. However the components are accurate enough to execute these tests.

Test for clause 5.5.2.4 is done with prototype R2.1. Instead of additional load on roller tracks there is 6 pallets on upper track and 6 pallets on lower track.

SAMPLES NEEDED

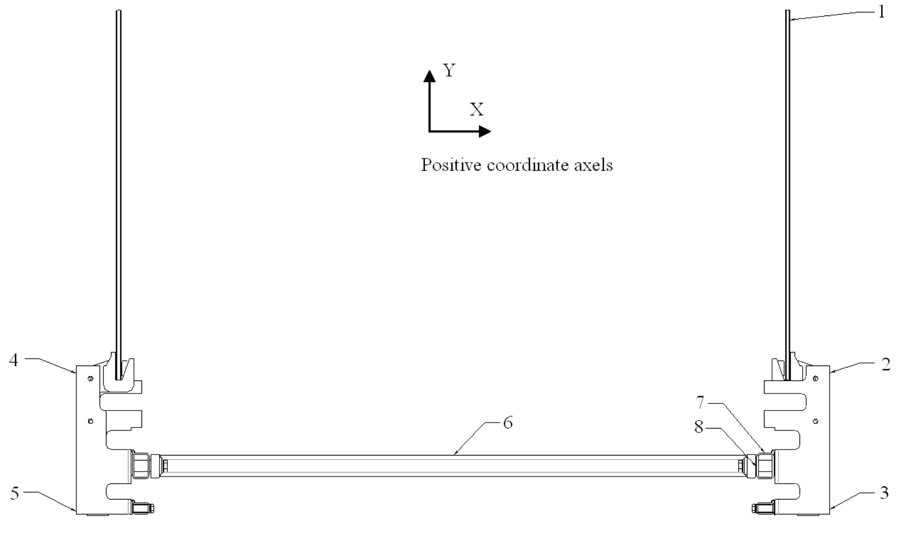
Appendix 12 table 1: Samples needed

Prototype	Middle section module, bracket type 3 R2.1
Manufacture No.	-
Nominal width	1400 mm
Height of balustrade	Nominal: 1000 mm Glass: 863 mm
Rise	0 mm
Length	Prototype 4000 mm Balustrade 3000 mm
Incline angle	0 degree
Speed	-
Level step quantity	-
Motor power	-

TEST PLAN

Test 1, according to clause 5.5.2.3

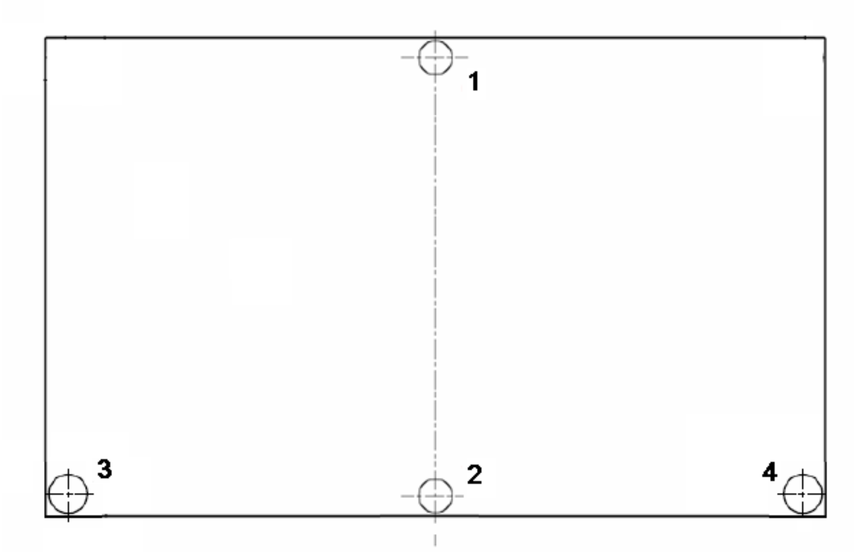
1) Mark test points according to the appendix 12 figure 3.
2) Place 8 dial indicators to the marked positions.appendix 12 figure 3.
    a. On top of the balustrade (horizontal movement)
    b. Back of the right side bracket, upper edge (horizontal movement)
    c. Back of the right side bracket, lower edge (horizontal movement)
    d. Back of the left side bracket, upper edge (horizontal movement)
    e. Back of the left side bracket, lower edge (horizontal movement)
    f. Middle of the cross beam (vertical movement)
    g. On top of the roller track (vertical movement)
    h. On the side of the roller track (horizontal movement)
3) Apply balustrade load according to the clause 5.5.2.3, 600 N in vertical direction and 730 N in horizontal direction.
4) Read the deflections from the dial indicators and record it.
5) Release the force and record the permanent deformation.
6) Perform steps 3, 4 and 5 two times.



Appendix 12 figure 3. Positions for dial indicators and positive coordinate axels

Test 2, according to clause 5.5.2.4

1) Mark test positions according to appendix 12 figure 4.
2) Place dial indicators according to the marked positions, appendix 12 figure 4.
3) Place dial indicator behind interior panel right at the market points, left and right.
4) Apply a force of 500 N acting at the marked points at right angles to the surface over an area of 25 cm^2.
5) Read the defection of glasses from the dial indicator which put behind glasses and record it.
6) Measure possible gaps between the balustrade glasses
7) Release the force and record the permanent deformation



Appendix 12 figure 4. Positions for dial indicators and positive coordinate axels in test 2

TEST RESULTS

Test according to clause 5.5.2.3

Test results for middle section module are presented in following tables.

Appendix 12 table 2: Bracket type 3 R2.1, 1st test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	18.96	18.86	0.31	0.28
2	0.96	0.96	0.04	0.04
3	-0.02	-0.01	-0.01	-0.01
4	0.50	0.41	0.03	0.03
5	0.08	0.08	0.00	0.00
6	0.10	0.10	0.01	0.01
7	0.16	0.16	0.01	0.01
8	0.18	0.19	0.02	0.02

Appendix 12 table 3: Bracket type 3 R2.1, 2nd test results

Pos.	Deflection under load [mm]	Deflection after 10 min under load [mm]	Deformation after force released [mm]	Deformation after 10 min of force released [mm]
Load	600N Lateral 730 N Vertical	600N Lateral 730 N Vertical	0 N Lateral 0 N Vertical	0 N Lateral 0 N Vertical
1	21.91	21.87	0.00	0.00
2	1.10	1.10	0.02	0.03
3	-0.02	-0.02	0.00	0.00
4	0.59	0.59	0.01	0.00
5	0.09	0.09	0.01	0.00
6	0.13	0.13	0.00	0.00
7	0.20	0.20	0.00	0.01
8	0.23	0.23	0.01	0.00

Test according to clause 5.5.2.4

Test results for middle section R2.1 are presented in appendix 12 table 4

Appendix 12 table 4: Test results according to clause 5.5.2.4

Position	Deflection under 500N [mm]		Deformation after force released [mm]	
	Left	Right	Left	Right
1	17.66	-	0.50	-
2	2.11	-	0.02	-
3	0.70	-	-0.01	-
4	0.55	-	-.0.01	-

CONCLUSION

Test 1

1) The glass panel was not broke or damaged during and after the test
2) For test according to clause 5.5.2.3, the balustrade was not broke or damaged during and after the test.
3) There were no permanent deformations.
4) Highest deflection value for balustrade is acceptable
    a. Biggest deflection is 30 % less compared to R2.0 design
5) The supporting structure works as a system in unwanted way
6) Left and right side are linked together and load causes deflections in both sides.
7) Roller track deflects under balustrade load

Test 2

1) For test according to clause 5.5.2.4, there were no gaps and no permanent deformations

LESSONS LEARNED

The structure is more stable and rigid with lower cross beam compared to the R2.0 design. However the structure is still behaving in unwanted way and transferring the movement of the balustrade from left side to right side and opposite.

The screw fixings between cross beams, roller tracks and bracket are most probably allowing the structure to deflect in this unwanted way.

The feeling of the balustrade is strong when leaning against it. When force is applied acting back and forth the balustrade deflections are higher than compared to static case. Tested prototype has 3 balustrade glasses fixed in to it and it can be assumed that with longer unit the movement of the balustrade will not be as great.

Comparison between original and conventional units

appendix 12 table 5 presents measured deflection values from different KONE units. Presented values are comparable but it needs to be kept in mind that tested units and prototypes have different length and the height of the balustrade is also varying.

Appendix 12 table 5: Comparison between measured balustrade deflections

Unit	Autowalk	Autowalk	Autowalk / Ramp	Escalator
Type	Self-supporting bracket system R2.1	InnoTrack™ prototype 5	AJV / RJV	MAP1 Prototype 2
Document number	LAB-54.04.020	LAB-54.04.008	LAB-54.04.010	LAB-54.04.014
Design stage	Prototype	Released	Released	Released
Balustrade height	1000 mm	1000 mm	1000 mm	1100 mm
Glass height	863 mm	863 mm	795 mm	831 mm
Deflection under balustrade load 5.5.2.3	Top max: 21.91 mm	Top max: 14.82 mm	Not measured	Not measured
Deflection under 500N vertical load 5.5.2.4	Top max: 17.66 mm	Top max: 10.21 mm	Top max: 18.26 mm	Top max: 14.27 mm
	Lower end: 0.70 mm	Lower end: 0.29 mm	Lower end: 0.27 mm	Lower end: 0.30 mm

According to comparison there is clear difference of the deflection values between original design and self-supporting bracket system. When balustrade load is applied according to the clause 5.5.2.3 the deflection of the balustrade in original design is 32.5 % less than in self-supporting bracket system. When load according to clause 5.5.2.4 is applied the difference is 42.2 %.

The difference between percentages is most probably due to the reason that in self-supporting bracket system the vertical load is acting against lateral load when balustrade load is applied. The reaction forces are balancing each other. When only vertical load is applied this doesn't happen and therefore the difference is bigger.

There is also remarkably big difference on the deflection value of the lower end of the balustrade when 500N load is applied vertically. This indicates that the fixing of the glass holder is not as rigid in tested system as it is in conventional units.

Major difference between original design for InnoTrack™ and self-supporting bracket system is that original design behaves symmetrically respect to the longitudinal centerline when balustrade load is applied. Original design is more rigid and movement of the left balustrade does not reflect highly to the right side.

Due to the design where roller track is fixed to the same bracket that the balustrade it is possible to excite the balustrade to oscillate by exciting the pallet in certain frequency.

DEVELOPMENT ACTIONS

Decide acceptable level for the balustrade deflection with certain load and design accordingly

Measure the nominal frequency of the balustrade and study the possibility for the balustrade to be excited to oscillate.

Appendix 13. Vibration test R2.1

PURPOSE OF THE TEST

This test is to measure vibrations on balustrade glass. Tests are done to find out the natural frequency of balustrade system fixed in self-supporting bracket system for moving walk. Target is to verify that the pedestrian excitation can’t excite the balustrade to oscillate.

Additional tests are done to InnoTrack^{TM} middle section prototype 5 (Schiphol design) and MAP 2 escalator (complete unit). These tests are to get reference results from exciting products.

ACCEPTANCE CRITERIA

In case of the tested prototype (self-supporting bracket system) for InnoTrack^{TM} moving walk there are three different causes for vibration that are taken account in this test. These are causing certain frequencies and the natural frequency of the system needs to be different from these. First studied vibration is pedestrian excitation, second is caused by reverser system and third by the travelling speed of the pallet band and span between support points.

Longitudinal and vertical vibrations of the balustrade system are not considered to be critical for the structure and there if no need to study vibration frequencies in vertical or longitudinal direction. This assumption is considered to be acceptable because experience has shown that it is highly unlikely that balustrade would vibrate in longitudinal or vertical direction.

Based on the studies presented in next chapter the acceptable natural frequency of the tested balustrade system is 7 Hz or more in lateral direction when excitation is on the pallet. When excitation comes from the reverser system the acceptable limit is 4 Hz or more. These criterions are only valid in presented three cases. These cases are in limits of a normal use of a moving walk. Vibrations caused by misuse must be studied separately.

If the natural frequency of the tested system is same as in reference case test for InnoTrack^{TM} prototype 5 it can be concluded that frequency is acceptable. This is due to the reason that experience has shown that original design has no vibration issues for the balustrade.

Study for the vibration frequencies of the InnoTrack™ moving walk

Pedestrian excitation

Pedestrians will cause different vibration frequencies in different directions. In case of moving walk the pedestrian excitation is not likely to arouse vibrations in longitudinal direction. This is due to the reason that the pallets are not fixed to the structure and therefore can't transfer the vibration in longitudinal direction.

Vertical and lateral vibration on top of the pallets will cause lateral movement on the balustrade. This is due to the design of the structure. Therefore vertical and lateral pedestrian excitation frequencies are critical frequencies.

Appendix 13 figure 1**Error! Reference source not found.** presents critical range of natural frequencies of footbridges with pedestrian excitation. Data is based on studies done in RWTH Aachen University. This data does not contain information of frequencies when pedestrians are running or jogging. David E. Newland has gathered measured data when pedestrians are walking, jogging and running. This data is presented in appendix 13 figure 2.

4.2 Step 2: Check of critical range of natural frequencies

The critical ranges for natural frequencies f_i of footbridges with pedestrian excitation are:

- for vertical and longitudinal vibrations:

$$1{,}25\text{ Hz} \leq f_i \leq 2{,}3\text{ Hz}$$

- for lateral vibrations: $0{,}5\text{ Hz} \leq f_i \leq 1{,}2\text{ Hz}$

Footbridges with frequencies for vertical or longitudinal vibrations of

$$2{,}5\text{ Hz} \leq f_i \leq 4{,}6\text{ Hz}$$

might be excited to resonance by the 2nd harmonic of pedestrian loads [1]. In that case, the critical frequency range for vertical and longitudinal vibrations expands to:

$$1{,}25\text{Hz} \leq f_i \leq 4{,}6\text{Hz}$$

Lateral vibrations are not effected by the 2nd harmonic of pedestrian loads.

Note: A vertical vibration excitation by the second harmonic of pedestrian forces might take place. Until now there is no hint in the literature that onerous vibration of footbridges due to the second harmonic of pedestrians have occurred.

Appendix 13 figure 1. Critical range of natural frequencies of footbridges with pedestrian excitation.[1]

	Pacing frequency f (Hz)	Forward speed V (m/s)	Stride length L (m)	Vertical fundamental frequency F_{vert} (Hz)	Horizontal fundamental frequency F_{lat} (Hz)
Slow walk	1.7	1.1	0.60	1.7	0.85
Normal walk	2.0	1.5	0.75	2.0	1.0
Fast walk	2.3	2.2	1.00	2.3	1.15
Slow running (jogging)	2.5	3.3	1.30	2.5	1.25
Fast running (sprinting)	>3.2	5.5	1.75	>3.2	>1.6

Appendix 13 figure 2. Data on walking and running [2]

[1] Design of Footbridges – Guideline; HILVOSS; Research Fund RFS2-CT-2007-00033, RWTH Aachen University.

[2] Pedestrian Excitation of Bridges – Recent Results; David E. Newland; University of Cambridge, Cambridge CB2 1PZ, England

Limits for critical natural frequencies for pedestrian excitation are concluded based on the presented data. These frequencies are presented in appendix 13 table 1.

Appendix 13 table 1: Limits for natural frequencies of a moving walk

Direction	Vibration frequency 1st harmonic [Hz]	Vibration frequency 2nd harmonic [Hz]
Vertical	$1.25 \leq f \leq 3.20$	$1.25 \leq f \leq 6.40$
Lateral	$0.50 \leq f \leq 1.60$	$0.50 \leq f \leq 3.20$
Longitudinal	$1.25 \leq f \leq 3.20$	$1.25 \leq f \leq 6.40$

Pallet reverser

Pallet reverser system for InnoTrack™ causes vibrations for the pallet band in longitudinal direction. Due to the reaction forces in reverser sprocket the vibration is also prone to cause movement in the balustrade of the tension head. This vibration is in lateral direction. Frequency of this vibration is depending on the pallet band speed and can be calculated according to equation 1. Appendix 13 table 2 presents the frequency respect to travelling speed when the span between chain connectors is 0.506 m.

$$f_{reverser} = \frac{v}{s} \tag{1}$$

Where *v* is the travelling speed of the pallet band [m/s] and *s* is the span between the chain connector [m].

Appendix 13 table 2: Vibrations from pallet reverser

Speed [m/s]	Vibration frequency 1st harmonic [Hz]	Vibration frequency 2nd harmonic [Hz]
0.75	1.48	2.96
0.65	1.28	2.56
0.50	0.94	1.88

Span between support points

Passenger travelling on pallet band in certain speed causes vibrations to the structure. Frequency can be calculated from equation 2. Appendix 13 table 3 presents the frequency respect to travelling speed when the span between support points is 1 m.

$$f_{pallet\_band} = \frac{v}{p} \qquad (2)$$

Where v is the travelling speed of the pallet band [m/s] and p is the span between the support points [m].

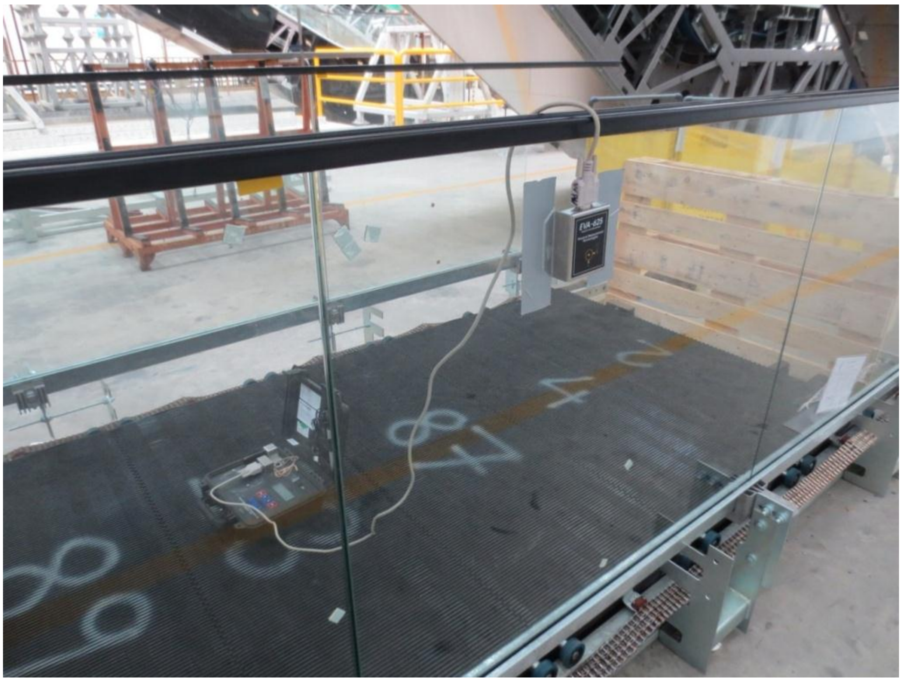
Appendix 13 table 3: Vibrations from pallet band

Speed [m/s]	Vibration frequency 1st harmonic[Hz]	Vibration frequency 2nd harmonic [Hz]
0.75	0.75	1.50
0.65	0.65	1.30
0.50	0.50	1.00

DESCRIPTION OF THE TEST SYSTEM

Self-supporting bracket system R2.1

Test to measure natural frequencies was done with InnoTrack™ preliminary prototype. PMT EVA-625 tool was used to measure acceleration rates in lateral direction at the measuring positions. Acceleration data is transferred to natural frequency. Vibrations of the prototype were measured from both left and right side balustrades. Lateral direction Z is normal to the surface of the balustrade glass panel. Test system for self-supporting bracket system is presented in appendix 13 figure 3.



Appendix 13 figure 3. Test system for self-supporting bracket system, bracket type 3

InnoTrack™ middle section module prototype 5

Test to measure natural frequencies was done with InnoTrack™ prototype 5. PMT EVA-625 tool was used to measure acceleration rates in lateral direction Z at the measuring position. Acceleration data is transferred to natural frequency. Vibrations of the prototype were measured from balustrade in one position.

MAP2 Pilot 3 Escalator

Test to measure natural frequencies was done with MAP 2 escalator. PMT EVA-625 tool was used to measure acceleration rates in lateral direction Z at the measuring position. Acceleration data is transferred to natural frequency. Vibrations of the prototype were measured from balustrade in one position. Test system for MAP2 Pilot 3 escalator is presented in appendix 13 figure 4.

Appendix 13 figure 4. Test system for MAP2 Pilot 3 escalator

Measurement System Analysis

The measurement device PMT EVA-625 is an acceleration meter. Accelerations are measured respect to time and the data is converted to frequency spectrum with Fast Fourier Transform (FFT).

The conversion from acceleration to natural frequency is based on equations 3 and 4.

$$a = \frac{k}{m}\Delta x \tag{3}$$

Where a is acceleration [m/s^2], k is spring constant [N/m], m is mass [kg] and Δx is spring extension [m]

$$f_N = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{4}$$

Where f_N is natural frequency [Hz], k is spring constant [N/m] and m is seismic mass [kg]

Test results are for a rigid body which means that based on these results it can’t be said for sure what are the actual modes and natural frequencies of the tested prototype. For this case when the prototype is in preliminary stage it is sufficient enough to have indication from the level where the actual natural frequency could be.

Self-supporting bracket system R2.1

Test system is not representing complete unit. Section is 4 meters long and attached balustrade is 3 meters long. Prototype is not representing complete unit and there are components missing such as skirting, cladding, inner and outer decking.

InnoTrack^{TM} middle section module prototype 5

Test system is not representing complete unit. Prototype is 4 meters long and balustrade is 3 meters long. Prototype is missing skirting profile and therefore the natural frequency is only indicative but it is comparable with the self-supporting bracket system.

MAP 2 Escalator

Tested prototype is complete unit. Vibration mode for the balustrade is different between the complete escalator and 4 meter long section. Therefore the results are not comparable.

SAMPLES NEEDED

Appendix 13 table 4: Samples needed

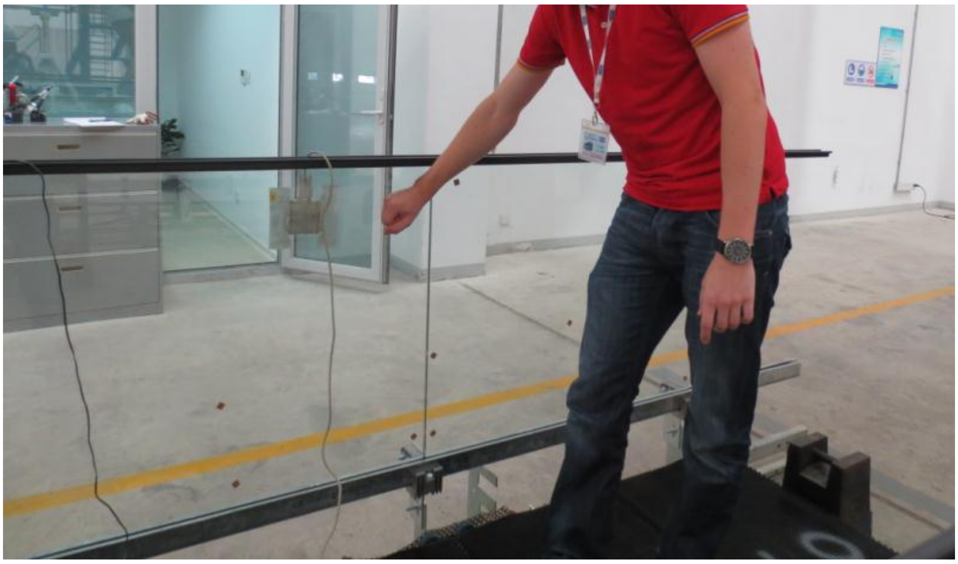
Prototype	Middle section module, bracket type 3 R2.1	MAP2, Pilot 3	Middle section module, Prototype 5
Manufacture No.	-	36037158	-
Nominal width	1400 mm	1000 mm	1400 mm
Height of balustrade	Nominal: 1000 mm Glass: 863 mm	Nominal: 1100 mm Glass: 831 mm	Nominal: 1000 mm Glass: 863 mm
Rise	0 mm	4500 mm	0 mm
Length	Prototype 4000 mm Balustrade 3000 mm	-	Prototype 4064 mm Balustrade 3048 mm
Incline angle	0 degree	30 degree	0 degree
Speed	-	0.5 m/s	-
Level step quantity	-	3/3	-
Motor power	-	7.5 kW	-

TEST PLAN

Tests 1-3, Self-supporting bracket system R2.1

Test 1

1) Attach the PMT EVA-625 tool to right balustrade glass of the tested prototype, appendix 13 figure 5
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data.
5) Repeat test 3 times



Appendix 13 figure 5. Measurement positions and action for test 1

Test 2

1) Attach the PMT EVA-625 tool to right balustrade glass of the tested prototype, Appendix 13 figure 6
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Jump on top of the pallets
4) Record the data
5) Repeat test 3 times

Appendix 13 figure 6. Measurement positions and action for test 2

Test 3

1) Attach the PMT EVA-625 tool to left balustrade glass of the tested prototype, Appendix 13 figure 7
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data
5) Repeat test 3 times

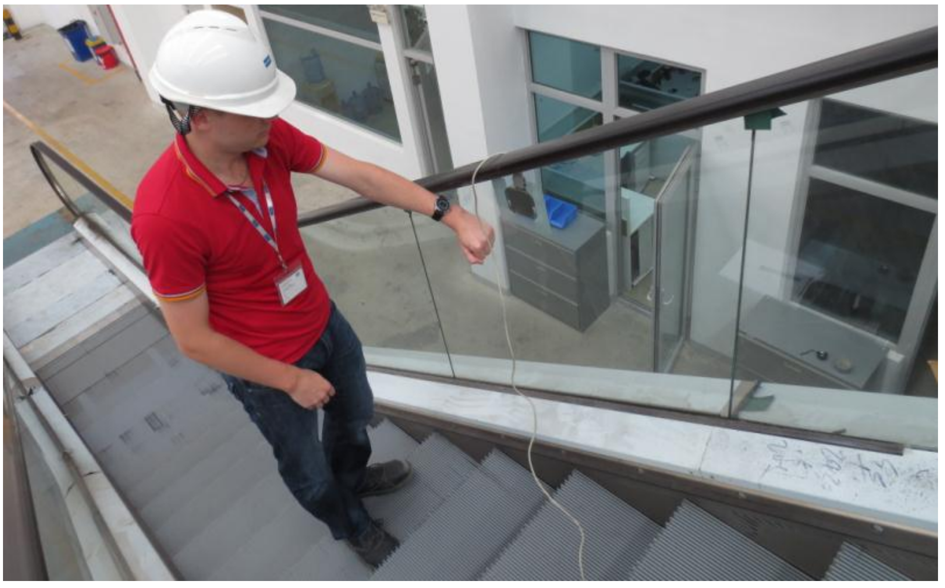
Appendix 13 figure 7. Measurement positions for test 3

Test 4, InnoTrack^{TM} middle section module prototype 5 (Schiphol design)

1) Attach the PMT EVA-625 tool to left balustrade glass of the InnoTrack^{TM} middle section prototype
    a. Same as in test 1
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data
5) Repeat test 3 times

Test 5, MAP 2 Escalator

1) Attach the PMT EVA-625 tool to left balustrade glass of the tested MAP 2 escalator prototype, Appendix 13 figure 8
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data
5) Repeat test 3 times



Appendix 13 figure 8. Measurement positions and action for test 4

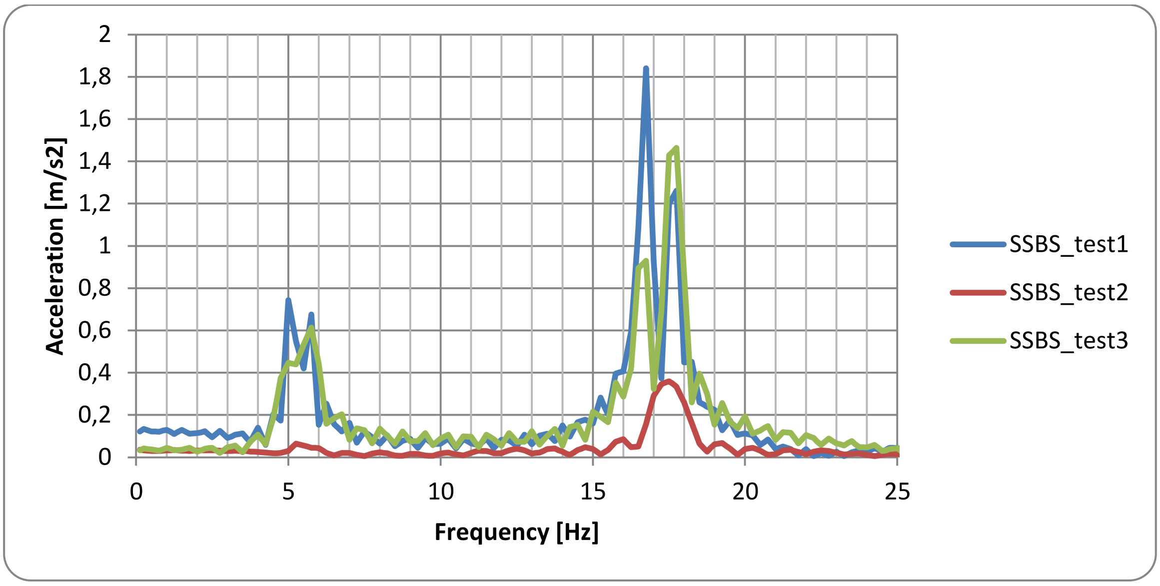
TEST RESULTS

Presented results are all vibrations in lateral direction, normal to the balustrade glass panel. Frequency is presented in frequency spectrum and vibrations are presented in acceleration respect to time.

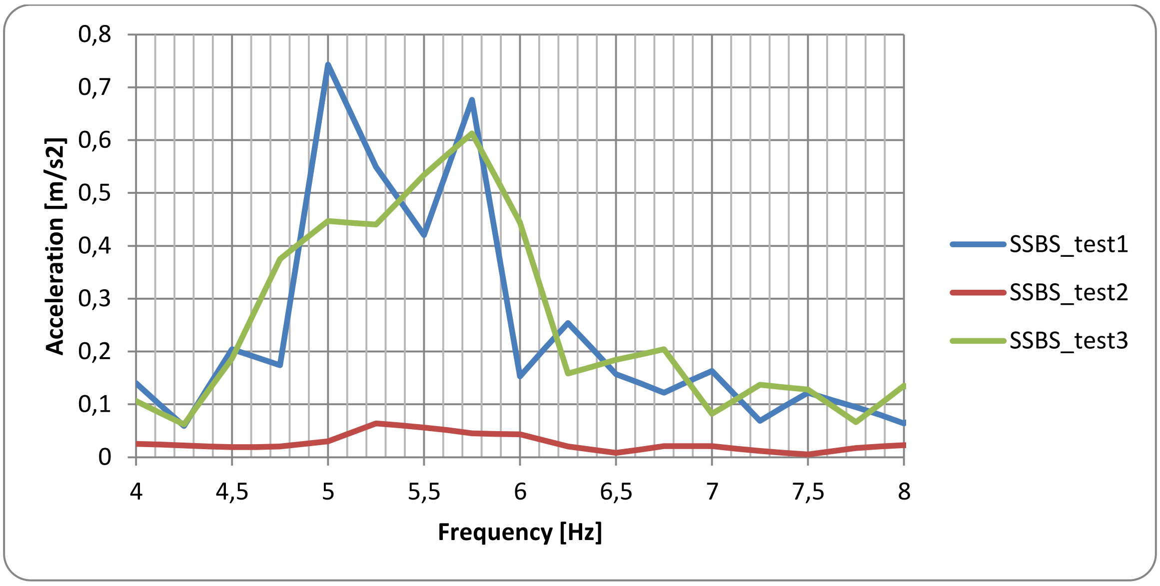
Natural frequency

Self-supporting bracket system R2.1

Results from tests 1, 2 and 3 are presented in appendix 13 figure 9 and appendix 13 figure 10.

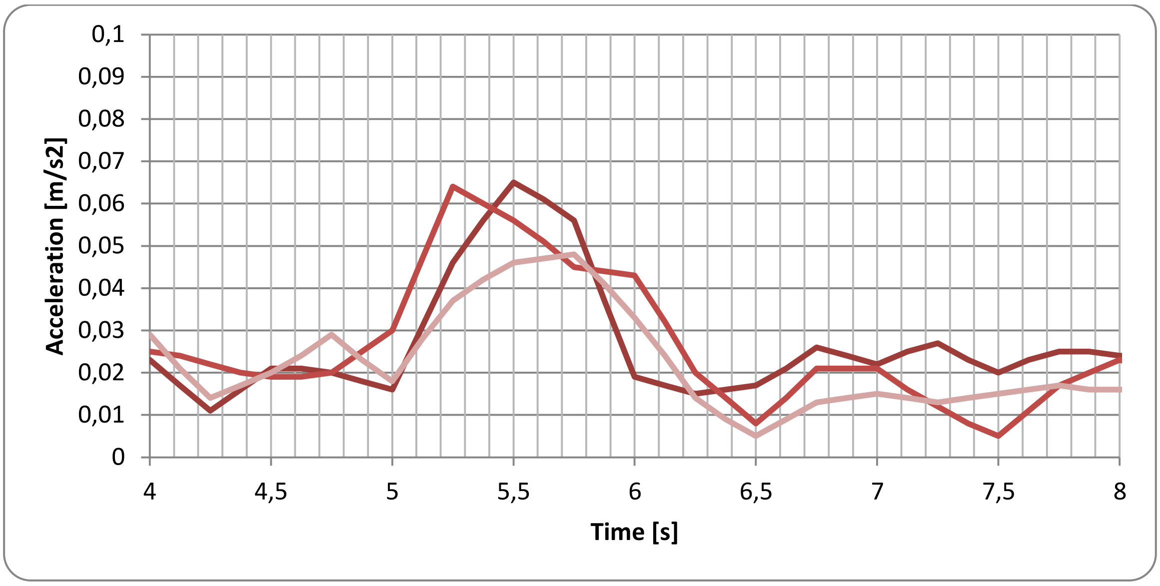


Appendix 13 figure 9. Test 1, 2 and 3, Frequency spectrum



Appendix 13 figure 10. Test 1, 2 and 3, Frequency spectrum from 4 Hz to 8 Hz

From the results can be seen that the first response frequency is at 5 Hz and the second is at 5.7 Hz. Next modes are above 16 Hz. The second test was repeated 3 times and the measured data from this test is presented in appendix 13 figure 11.

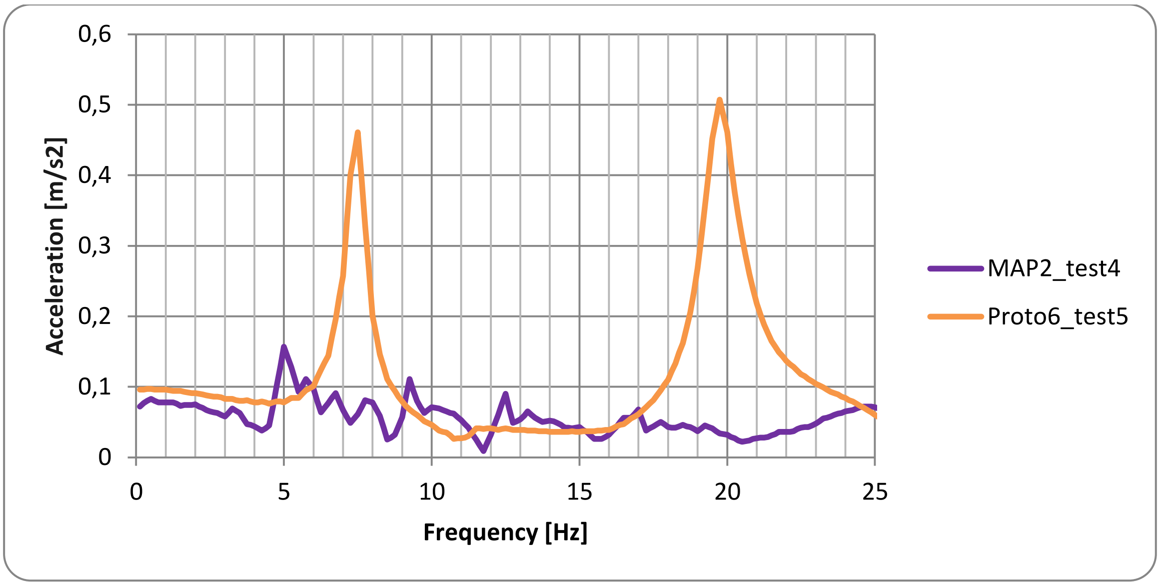


Appendix 13 figure 11. Test 2, Frequency spectrums

From the spectrum it can be seen that the each test has different peak. However they are all close to 5.5 Hz.

MAP2 Escalator and InnoTrack^{TM} prototype 5

Results from tests 4 and 5 are presented in appendix 13 figure 12.

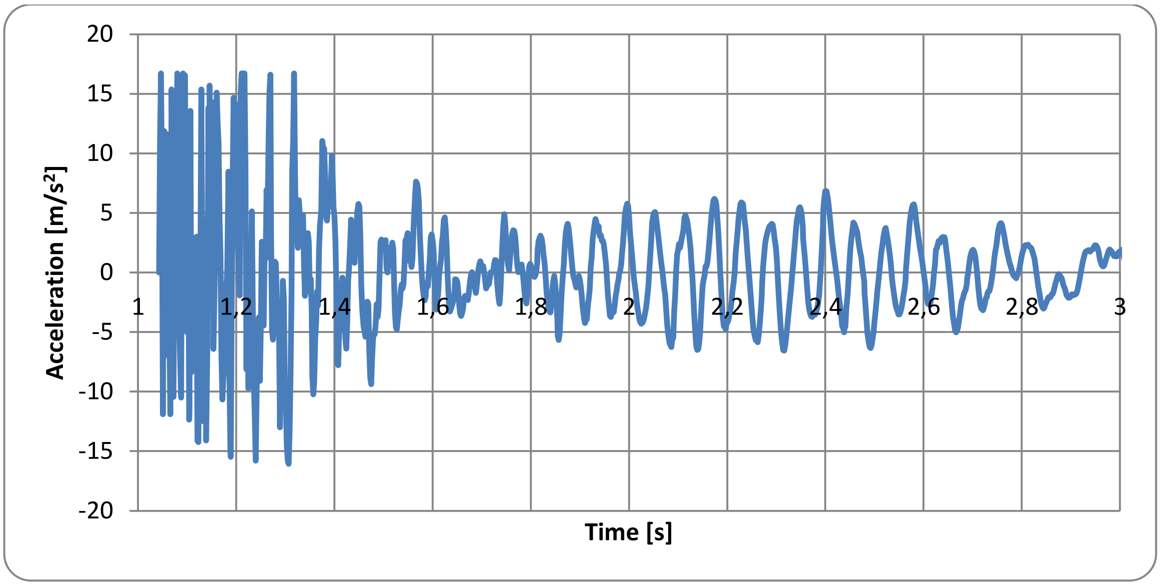


Appendix 13 figure 12. Test 4 and 5, Frequency spectrum

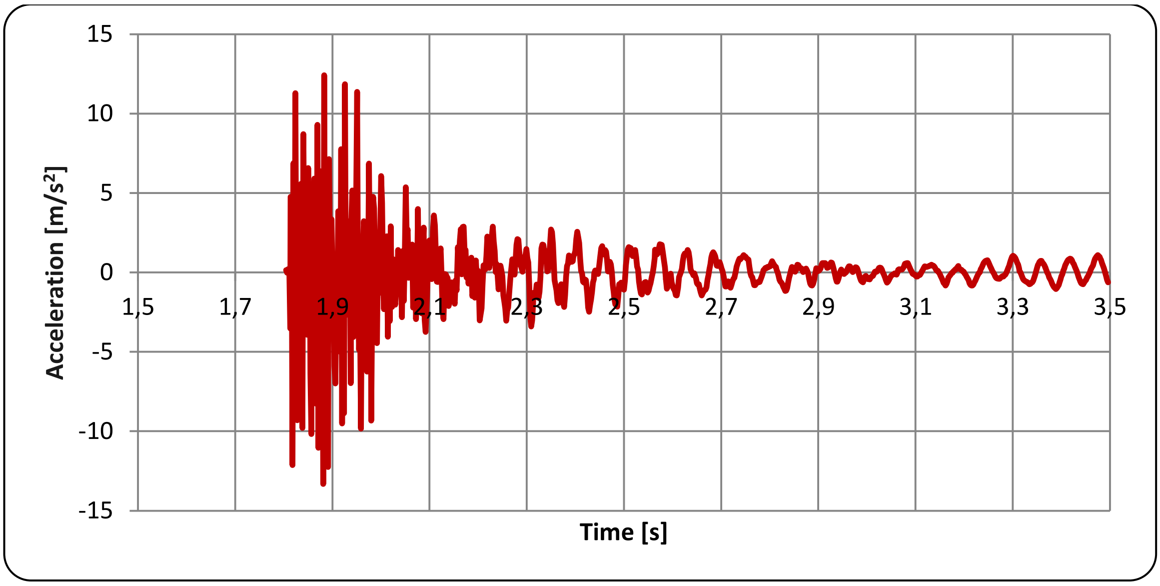
MAP2 escalator has first response frequency at 5 Hz. Second response frequency is 5.25 Hz and third 12.4 Hz. InnoTrack™ prototype 5 balustrade has first response frequency in 7.5 Hz and second in 19.8 Hz.

Vibration

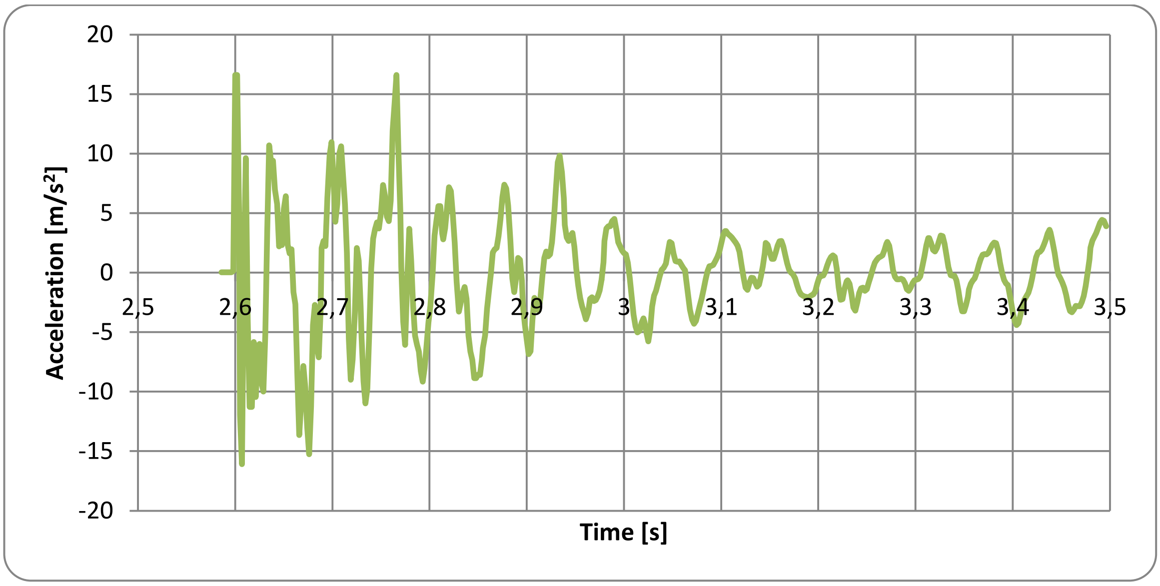
Self-supporting bracket system R2.1



Appendix 13 figure 13. Acceleration data from test 1

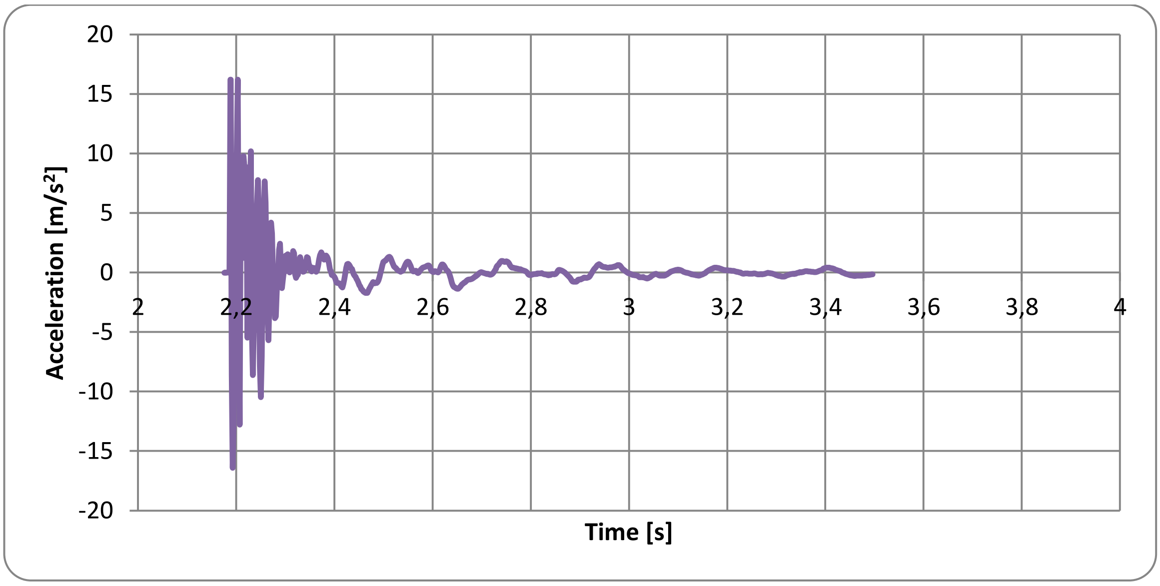


Appendix 13 figure 14. Acceleration data from test 2



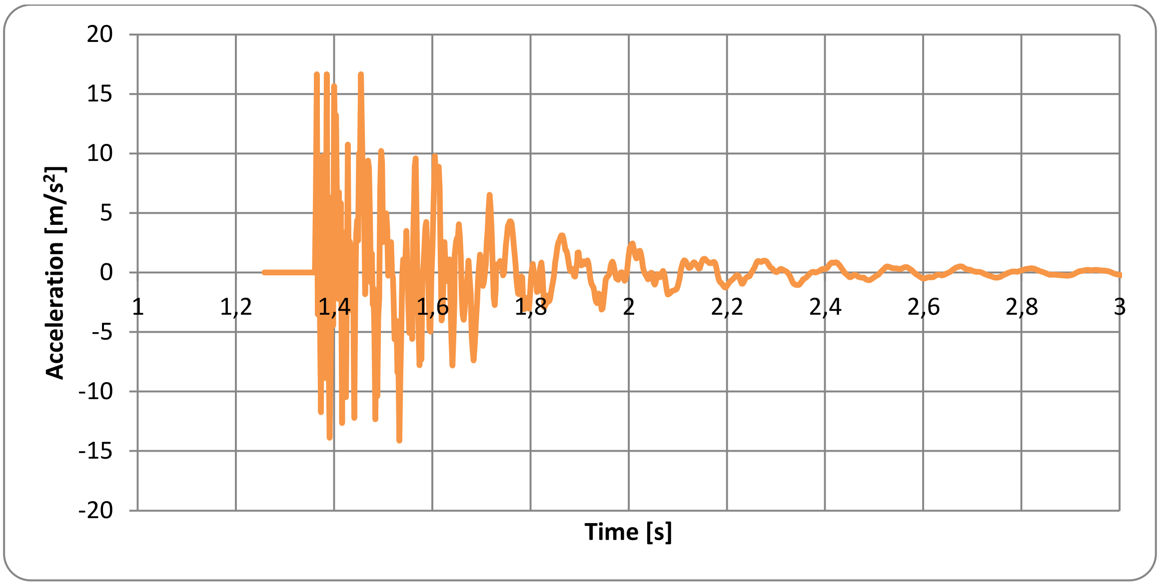
Appendix 13 figure 15. Acceleration data from test 3

MAP2 Escalator



Appendix 13 figure 16. Acceleration data from test 4

InnoTrack^{TM} prototype 5



Appendix 13 figure 17. Acceleration data from test 5

From the vibration results it can be seen that the decay of the acceleration is faster for MAP2 and InnoTrack^{TM} prototype 5 compared to the self-supporting bracket system.

CONCLUSION

- According to the results tested module of self-supporting bracket system has first response frequency at 5.0 Hz and second at 5.7 Hz
    - These modes can be excited by jumping on the pallet or striking the balustrade glass
- Pedestrian excitation can excite the balustrade to oscillate
    - 2nd harmonic frequency of jogging or running
- Structure is not acceptable for normal use
- Excitation from reverser system will not excite the balustrade to oscillate
    - 5.0 Hz frequency is the first mode that can be excited by the reverser system

- According to the results MAP2 Escalator has first response frequency at 5.0 Hz
    - Decay in the acceleration diagram is faster compared to self-supporting bracket system
    - Complete unit has different modes compared to short section
    - Response frequency of the MAP2 balustrade can't be compared directly with short section

- InnoTrackTM prototype 5 (original design) has first response frequency at 7.5 Hz
    - Decay in the acceleration diagram is faster compared to self-supporting bracket system

LESSONS LEARNED

Balustrade of a short section can be considered to work as pendulum and fixing point is a torsion spring. To increase the natural frequency of the prototype this fixing point needs to be modified. By modifying the fixing to be more rigid the natural frequency will be increased.

In complete unit the balustrade mode is different compared to the short section. In complete unit reciprocating motion of a single point causes longitudinal waves. These modes can be seen from the frequency spectrum from test 4. It is likely that when using self-supporting brackets the balustrade system would behave in similar way in complete unit.

DEVELOPMENT ACTIONS

The response frequency of the balustrade system needs to be higher when excitation comes from pallet band. Investigate how to increase the natural frequency of the balustrade system.

Appendix 14. Vibration test R2.4

PURPOSE OF THE TEST

This test is to measure vibrations on balustrade glass. Tests are done to find out the natural frequency of balustrade system fixed in self-supporting bracket system for moving walk. Target is to verify that the pedestrian excitation can't excite the balustrade to oscillate.

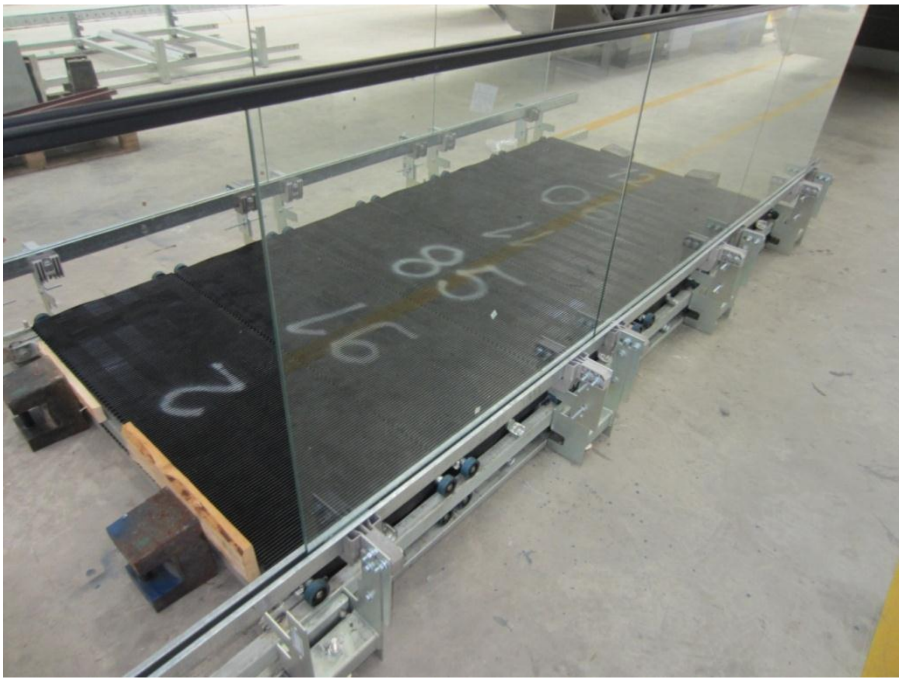
ACCEPTANCE CRITERIA

In case of the tested prototype (self-supporting bracket system) for InnoTrack^{TM} moving walk there are three different causes for vibration that are taken account in this test. These are same as presented in appendix 13.

DESCRIPTION OF THE TEST SYSTEM

Self-supporting bracket system R2.4

Test to measure natural frequencies was done with InnoTrack^{TM} preliminary prototype. PMT EVA-625 tool was used to measure acceleration rates in lateral direction at the measuring positions. Acceleration data is transferred to natural frequency. Vibrations of the prototype were measured from both left and right side balustrades. Lateral direction Z is normal to the surface of the balustrade glass panel. Test system is presented in appendix 14 figure 1



Appendix 14 figure 1. Test system for self-supporting bracket system, bracket type 3

Measurement System Analysis

The measurement device PMT EVA-625 is an acceleration meter. Accelerations are measured respect to time and the data is converted to frequency spectrum with Fast Fourier Transform (FFT). The conversion to natural frequency is presented in appendix 13.

Self-supporting bracket system R2.4

Test system is not representing complete unit. Section is 4 meters long and attached balustrade is 3 meters long. Prototype is not representing complete unit and there are components missing such as skirting, cladding, inner and outer decking.

SAMPLES NEEDED

Appendix 14 table 1: Samples needed

Prototype	Middle section module, bracket type 3 R2.4
Manufacture No.	-
Nominal width	1400 mm
Height of balustrade	Nominal: 1000 mm Glass: 863 mm
Rise	0 mm
Length	Prototype 4000 mm Balustrade 3000 mm
Incline angle	0 degree
Speed	-
Level step quantity	-
Motor power	-

TEST PLAN

Test 1

1) Attach the PMT EVA-625 tool to right balustrade glass of the tested prototype
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data.
5) Repeat test 3 times

Test 2

1) Attach the PMT EVA-625 tool to right balustrade glass of the tested prototype
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Jump on top of the pallets

4) Record the data
5) Repeat test 3 times

Test 3

1) Attach the PMT EVA-625 tool to left balustrade glass of the tested prototype
    a. 20 cm from handrail
2) Set PMT EVA-625 to take 512 samples per second
3) Knock the balustrade with fist, 30 cm from the tool
4) Record the data
5) Repeat test 3 times

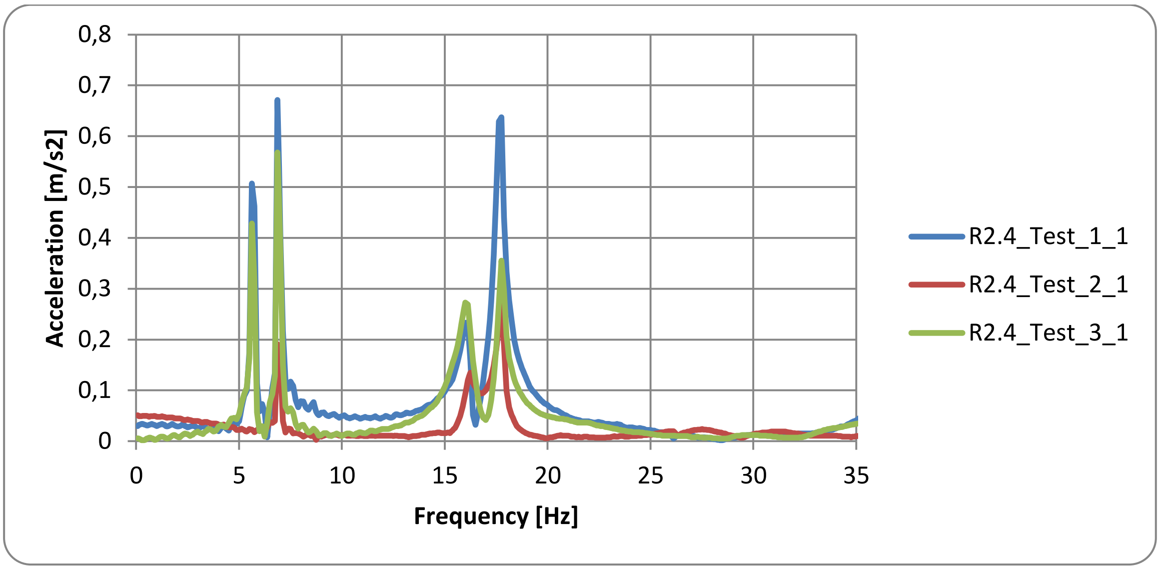
TEST RESULTS

Presented results are all vibrations in lateral direction, normal to the balustrade glass panel. Frequency is presented in frequency spectrum and vibrations are presented in acceleration respect to time.

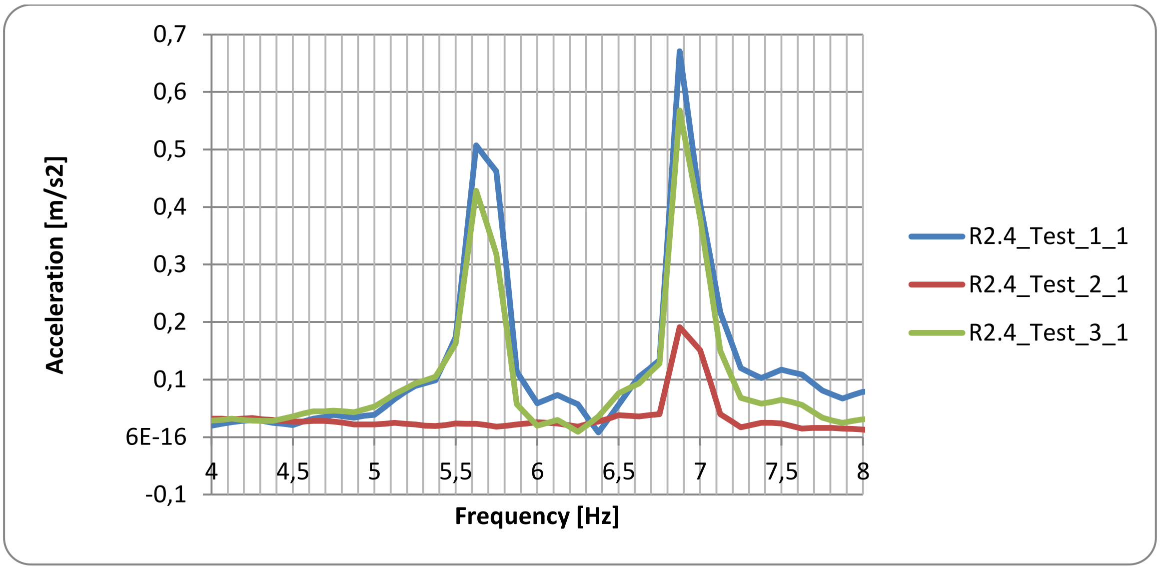
Natural frequency

Self-supporting bracket system R2.4

Results from tests 1, 2 and 3 are presented in appendix 14 figure 2 and appendix 14 figure 3.

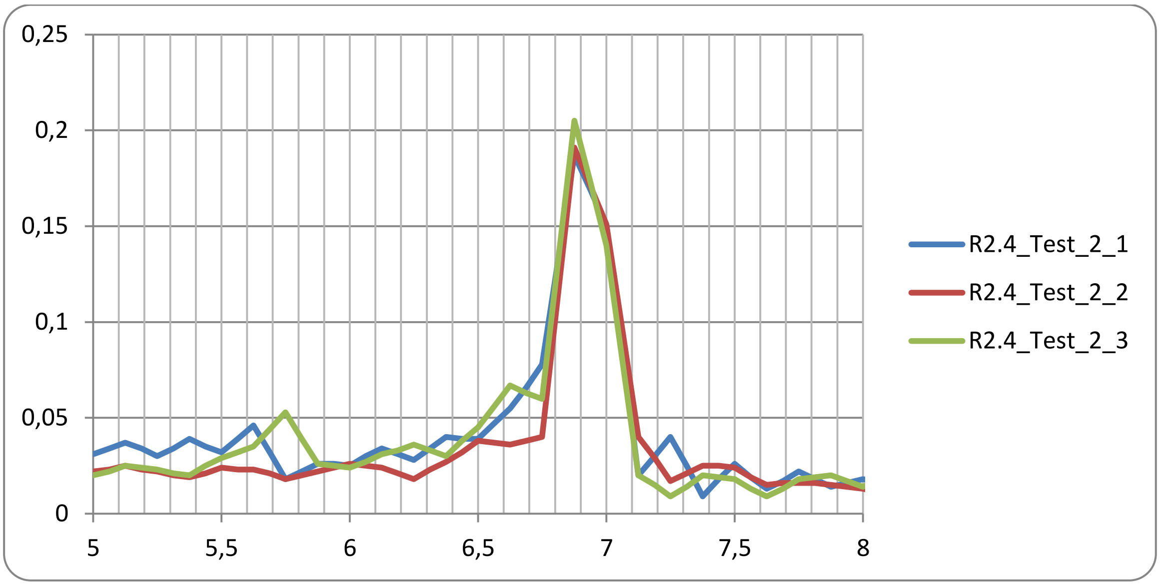


Appendix 14 figure 2. Test 1, 2 and 3, Frequency spectrum



Appendix 14 figure 3. Test 1, 2 and 3, Frequency spectrum from 4 Hz to 8 Hz

From appendix 14 figure 3 it can be seen that when balustrade is excited by striking the balustrade there is response frequency in 5.6 Hz and 6.9 Hz. When exciting the system by jumping on the pallet there is only response frequency at 6.9Hz. The second test was repeated 3 times and the measured data from this test is presented in appendix 14 figure 4.

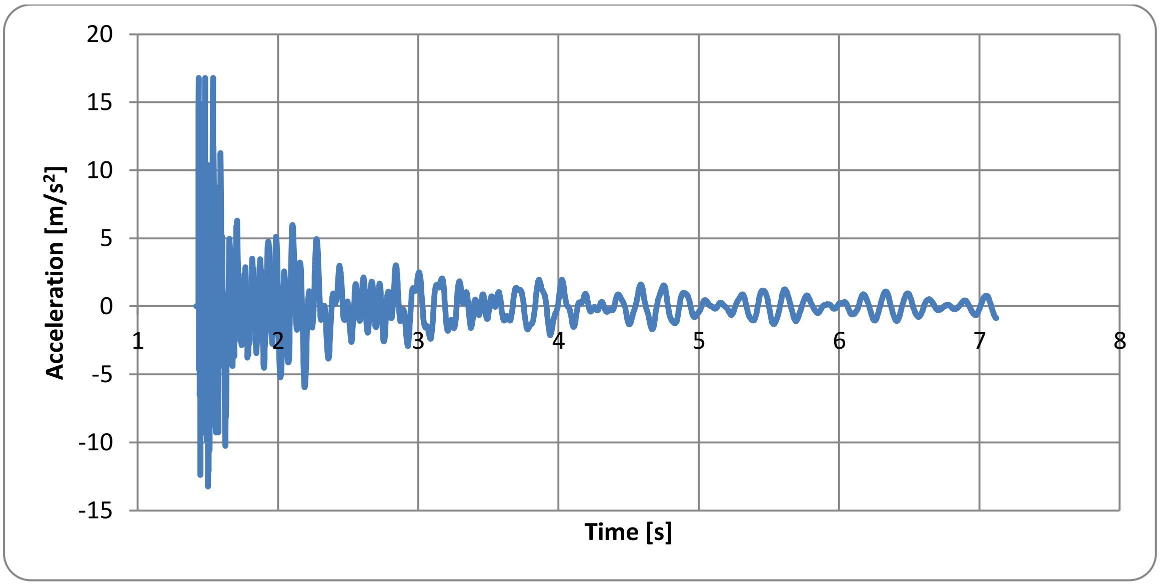


Appendix 14 figure 4. Frequency spectrums from test 2, Excitation by jump on the pallet

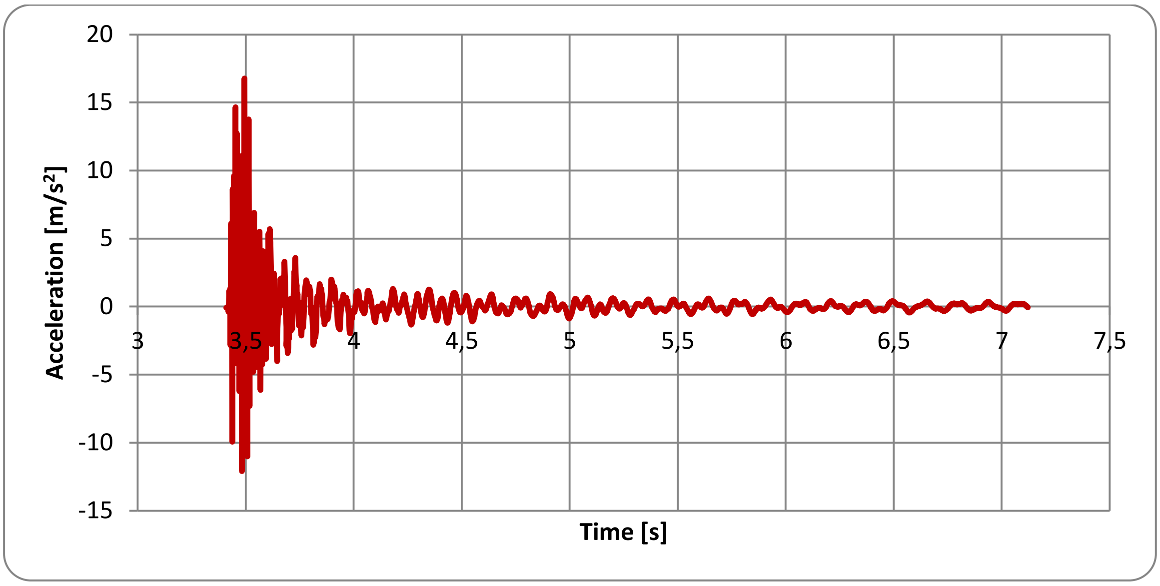
There is clear response frequency peak at 6.9Hz and no indications that the 5.6 Hz mode of the balustrade could be excited from the pallet.

Vibration

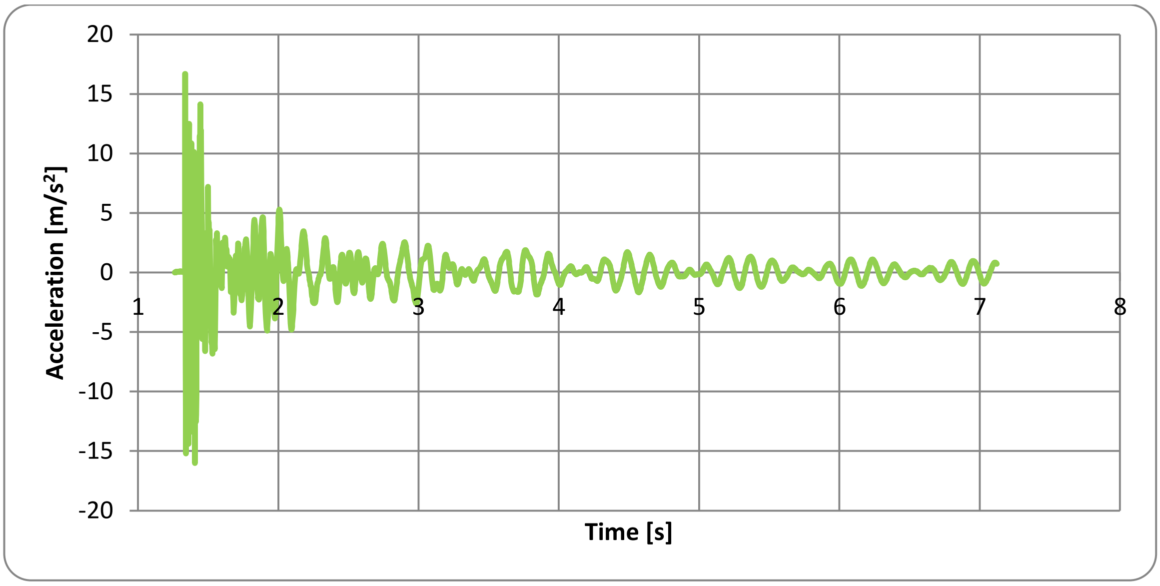
Self-supporting bracket system R2.4



Appendix 14 figure 5. Acceleration data from test 1



Appendix 14 figure 6. Acceleration data from test 2



Appendix 14 figure 7. Acceleration data from test 3

CONCLUSION

Frequency

- Balustrade system has response frequencies at 5.6 Hz and 6.9 Hz
    - Higher modes are above 10 Hz and can be ignored
- Pedestrian excitation will not excite the balustrade to oscillate
    - 6.9 Hz frequency is the first mode that can be excited from the pallet
    - 6.9 Hz is close to the set limit of 7 Hz and can be accepted

- Excitation from reverser system will not excite the balustrade to oscillate
    - 5.6 Hz frequency is the first mode that can be excited by the reverser system

Vibration

- Decay of the vibration is faster when comparing to the R2.1 design.

LESSONS LEARNED

It is characteristic for the balustrade glass to have response frequency at around 5 Hz when using aluminum die cast glass holder. Fixing method needs to be completely different to increase the frequency dramatically, for example a longitudinal support like in original design of InnoTrack^{TM}.

Appendix 15. Supporting structure calculations R2.5

PURPOSE OF THE ANALYSIS

Target is to verify by calculation mechanical strength of the supporting structure according to EN 115-1.

Clause: 5.2.5

ACCEPTANCE CRITERIA

5.2.5 Structural design

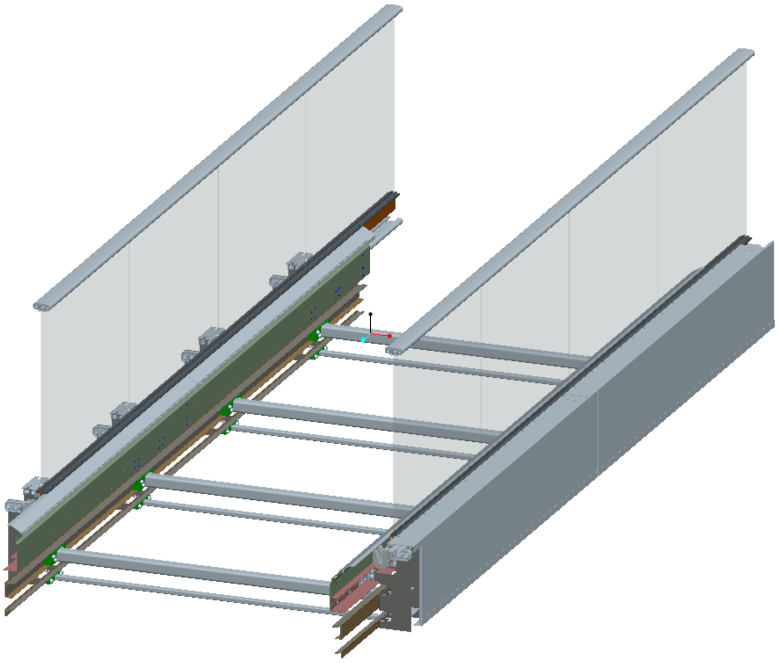
The supporting structure shall be designed in a way that it can support the dead weight of the escalator or moving walk plus a rated load of 5000 N/m2. It shall be calculated in accordance with EN 1993-1-1.

NOTE Load carrying area = (nominal width z_1 (see Figure 3) of the escalator or moving walk) x (distance l_1 between the supports)

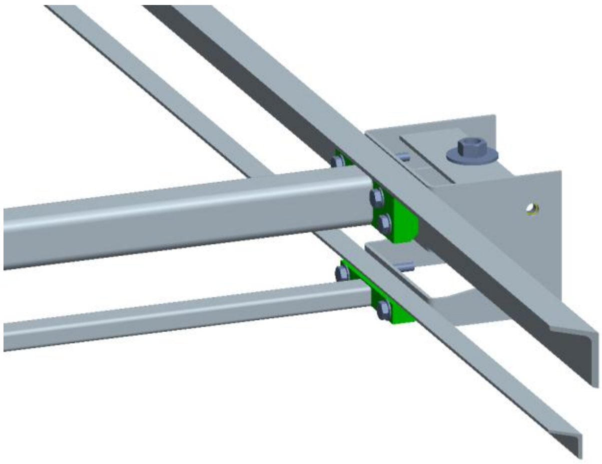
Based on the rated load, the maximum calculated or measured deflection shall not exceed 1/750 of the distance l_1 between the supports.

Description of the 3D model - Geometry

The geometry for the calculation model is designed with PRO/Engineer wildfire 4.0. Calculation model is to calculate the supporting structure of the middle section module. Complete module is presented in appendix 15 figure 1. The actual supporting structure is presented in appendix 15 figure 2.



Appendix 15 figure 1. Middle section module for InnoTrack^{TM}



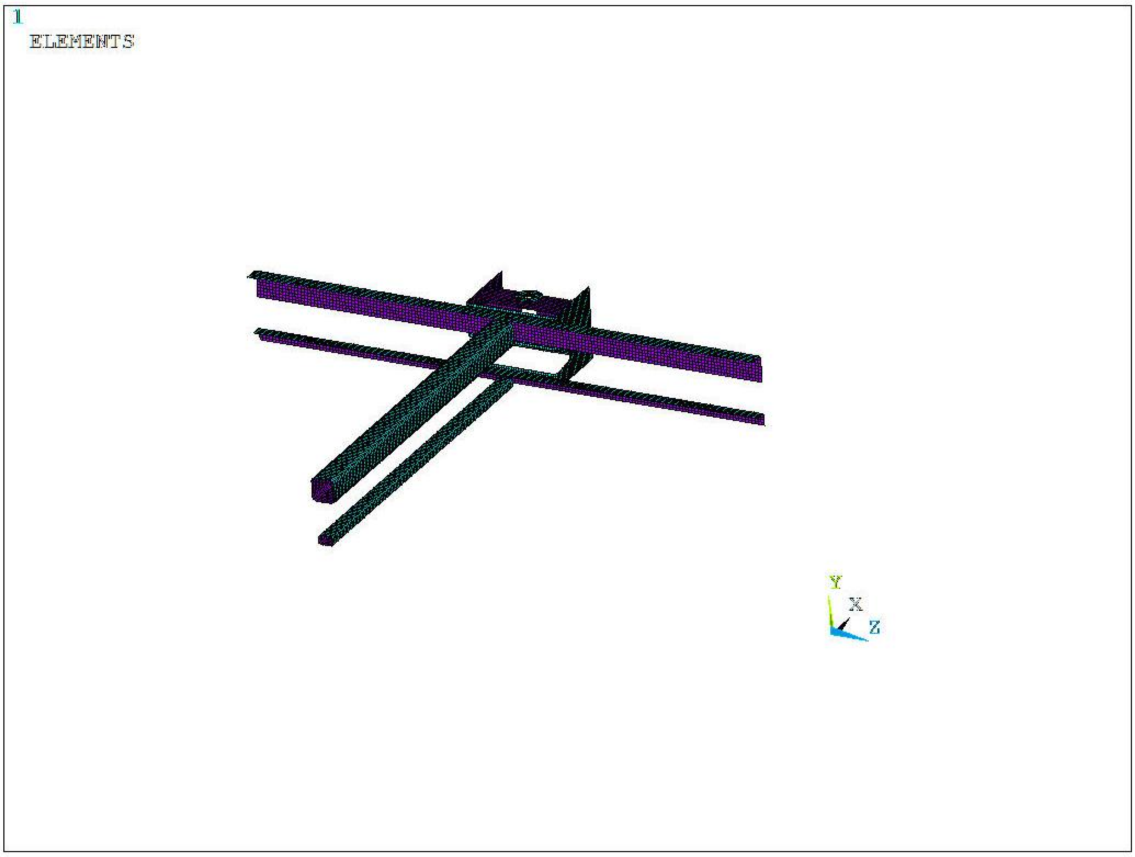
Appendix 15 figure 2. Supporting system for InnoTrack^{TM} middle section module

Description of the calculation models

The structure under the analysis is symmetric respect to the center line and also between each supporting bracket. There are two different calculation models in this report. The difference between these two models is in the boundary constraints of the supporting foot and therefore also in the element mesh. Both calculation models are one eight of the actual middle section module. Coordinate system, units and material parameters are same for both models.

Coordinate system

The coordinate system for both calculation models is equal and is presented inappendix 15 figure 3.



Appendix 15 figure 3. Coordinate system of the calculation model 1

Units

Appendix 15 table 1: Units used in this report

Name	E	Length	Mass
Unit	MPa	mm	t

Material parameters

Appendix 15 table 2: Material parameters

Material ID	Components	Density	E	μ
1	Supporting structure	7.85e-9	2.06e5	0.3

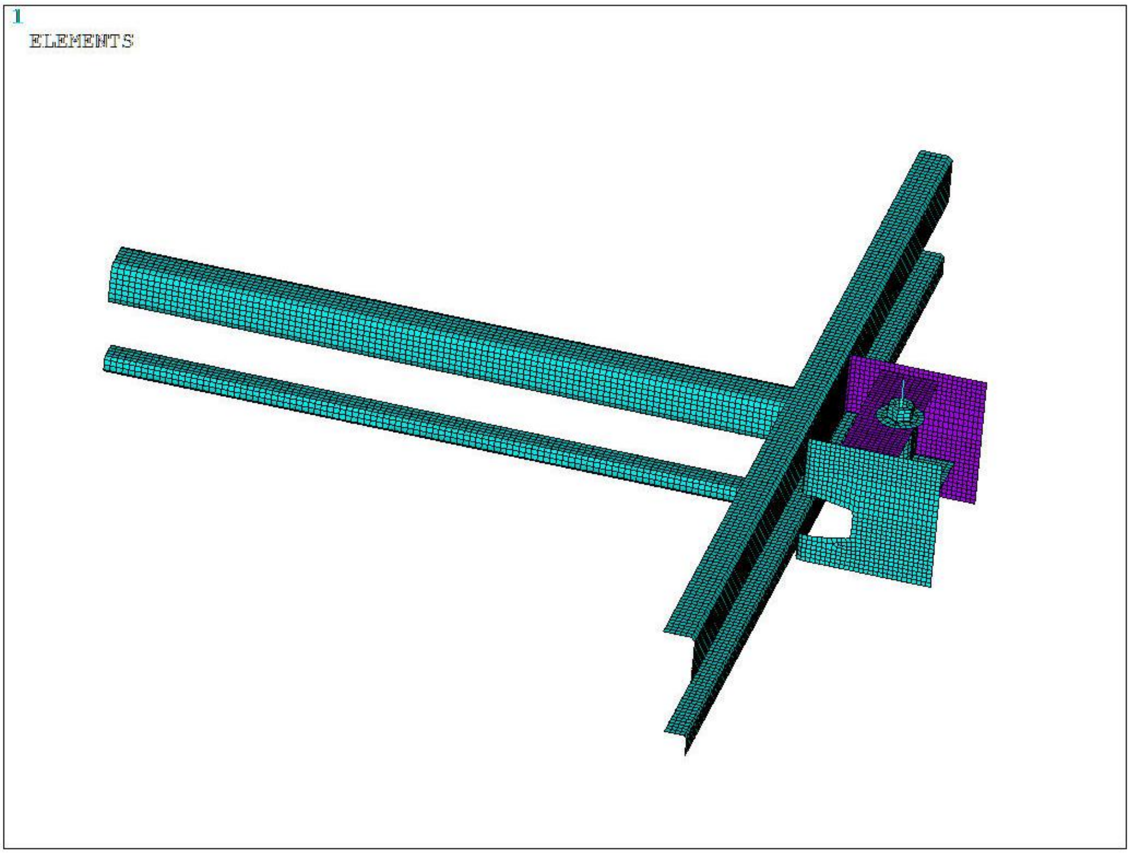
CALCULATION MODEL 1

Element mesh

Used elements for calculation model 1 are presented in appendix 15 table 3 and the mesh is presented in appendix 15 figure 4.

Appendix 15 table 3: Used elements in calculation model 1

Element type	Name	Number of elements
Shell	Shell281	11647
Solid	Solid185	2138
Beam	Beam188	37

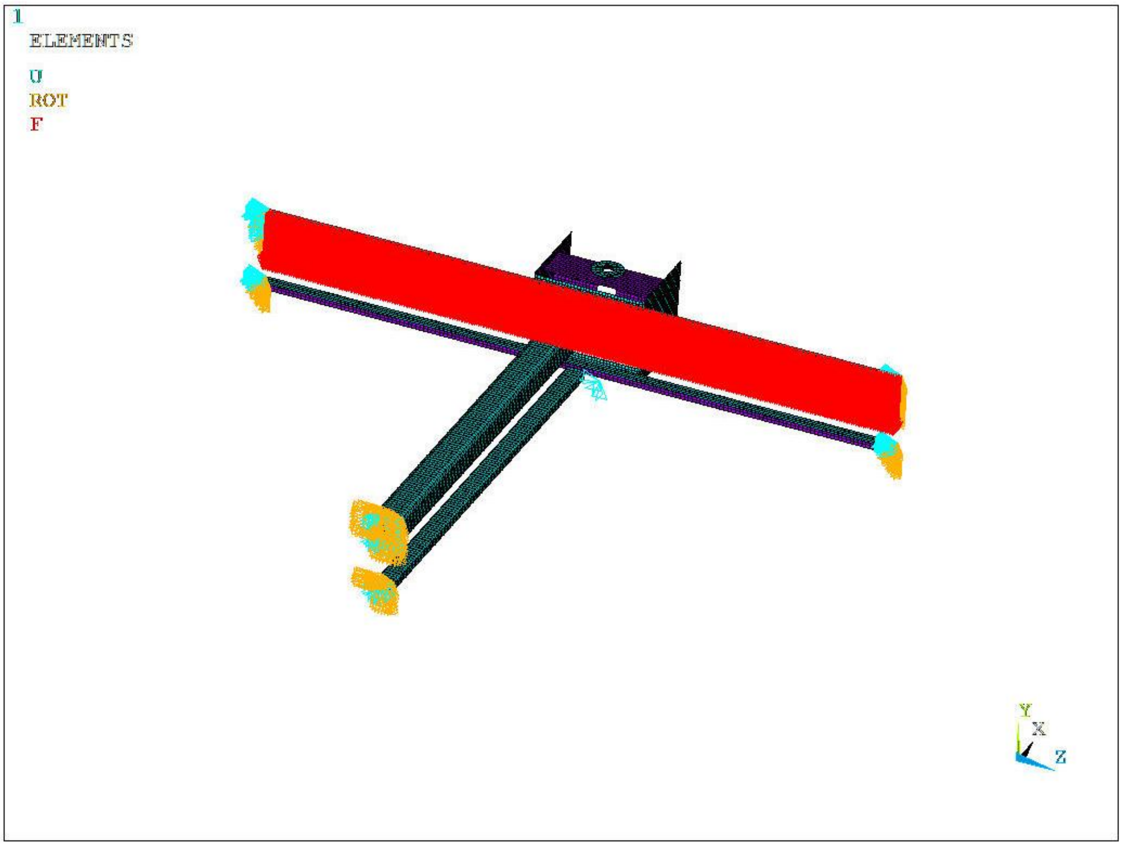


Appendix 15 figure 4. Element mesh for calculation model 1

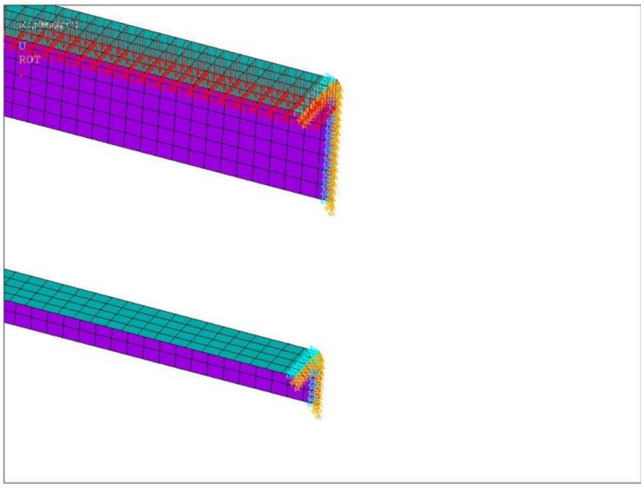
Boundary constraints

The boundary constraints for the structure are presented in following figures. The model uses symmetry. Free ends of the cross beams have fixed translation respect to the X-axis and fixed rotations respect to Z-axis. Both ends of the roller tracks have fixed translation respect to the Z-axis and fixed rotation respect to the X-axis. The adjustable foot has fixed translations respect to all axes.

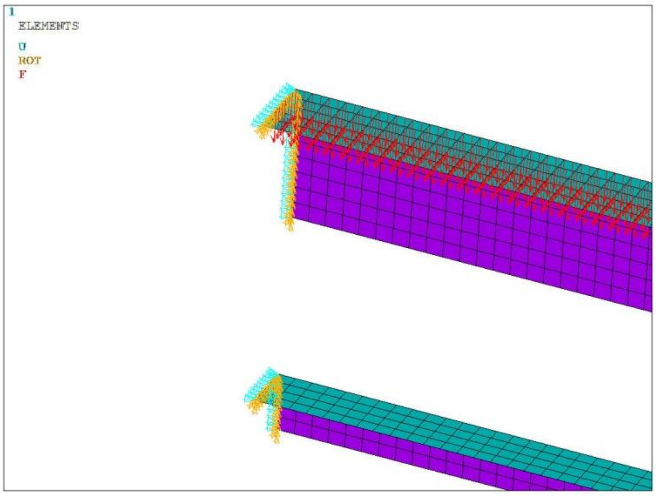
The load is applied on top of the upper roller track. The load is distributed over the whole length of the profile and in width of 25 mm from the waist of the profile. Load is calculated from the rated load of the EN 115 and is 4814.54 N acting along the Y-axis.



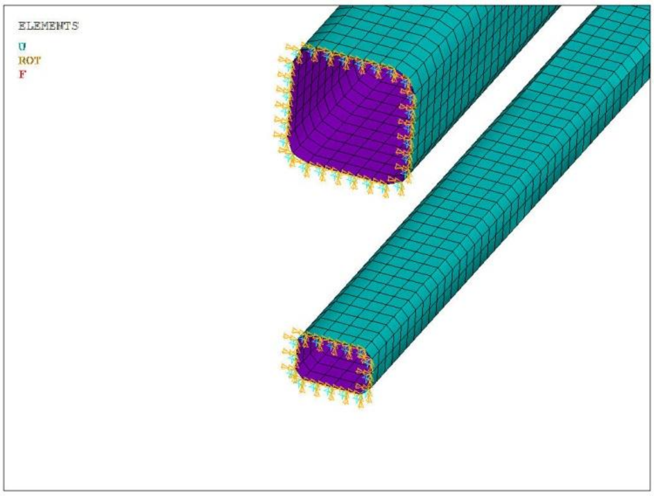
Appendix 15 figure 5. Boundary constrains of the calculation model 1



Appendix 15 figure 6. Detailed boundary constrains of the calculation model 1



Appendix 15 figure 7. Detailed boundary constrains of the calculation model 1



Appendix 15 figure 8. Detailed Boundary constraints of the calculation model 1

CALCULATION MODEL 2

Element mesh

Used elements for calculation model 2 are presented in **Error! Reference source not found.**. The mesh is equal to the mesh in calculation model except the adjustable foot is 50 mm longer and there is 10 more beam elements.

Appendix 15 table 4: Used elements in calculation model 2

Element type	Name	Number of elements
Shell	Shell281	11647
Solid	Solid185	2138
Beam	Beam188	47

Boundary constraints

The boundary constraints are same as in calculation model 1 except the position of the constraint in adjustable foot is 50 mm lower due to the different geometry. This is due to the possibility that the foot can be adjusted.

CALCULATION MODEL ANALYSIS

All components in the calculation model are simplified to be bonded to each other. In reality the structure has screw fixing between upper and lower roller track. These fixings are calculated separately. The tensioning force from the screws is ignored. It is assumed that the screw connection is strong enough and components can be simplified to be bonded.

The foot of the bracket has spherical joint. The screw of the foot is modeled by using beam elements and the connection end has fixed translations and free rotations. The position of the constraint is varying between two load calculation models. These two models are representing the highest and lowest position of the foot.

The load is calculated according to the equation 1. The whole load is applied on top of the upper roller track.

$$F_{RATED} = \frac{5000\frac{N}{m^2} \cdot A_{nominal} + m_{Deadweight} \cdot g}{8} \quad (1)$$

Given values:

Nominal area	$A_{Nominal}$	$5.6m^2$
Deadweight	$m_{Deadweight}$	1072kg
Acceleration of gravity	g	$9.81m/s^2$

$$F_{RATED} = \frac{5000\frac{N}{m^2} \cdot 1.4m \cdot 4m + (560kg + 32kg \cdot 16) \cdot 9.81\frac{m}{s^2}}{8} = 4814.54N$$

The deadweight of the structure is calculated by using the deadweight of the original design. The original middle section weighs 560 kg without the pallets. In this calculation the full load is applied on top of the upper roller track. This is due to the reason that the true weight of the new design is still unknown. Calculation model does not consider the gravity in to the calculation and therefore the deadweight is applied on the upper roller track. This can be considered to be the worst case.

Maximum energy ratio is calculated according to equation 2. Ratio and its element number are presented in appendix 15 table 5.

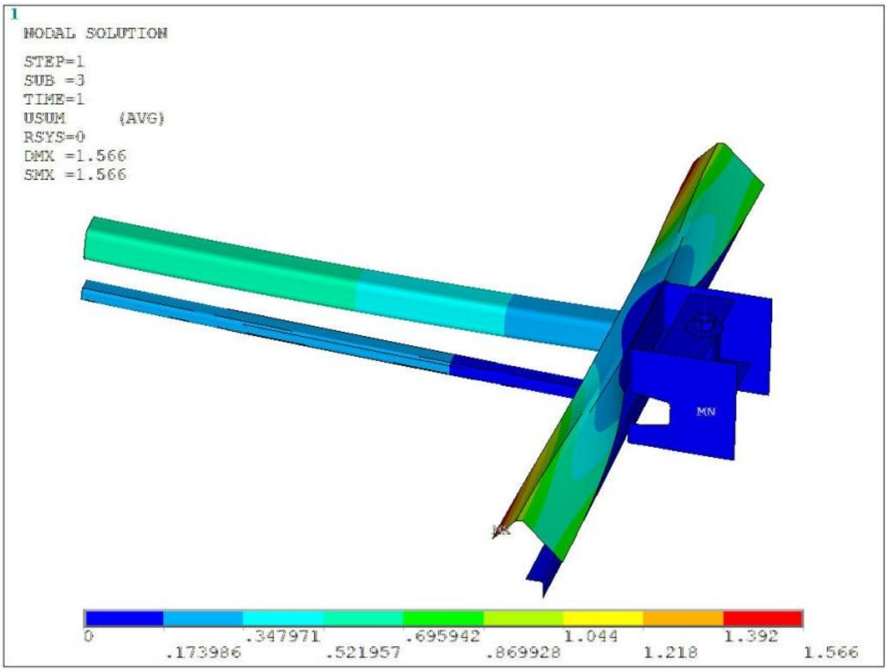
$$Maximum\ energy\ ratio = \frac{Artificial\ energy}{Total\ energy} \tag{2}$$

Appendix 15 table 5: Maximum energy ratio

Element	7827
Value	0.50213E-01

CALCULATION RESULTS

Stiffness of the structure, Calculation model 1

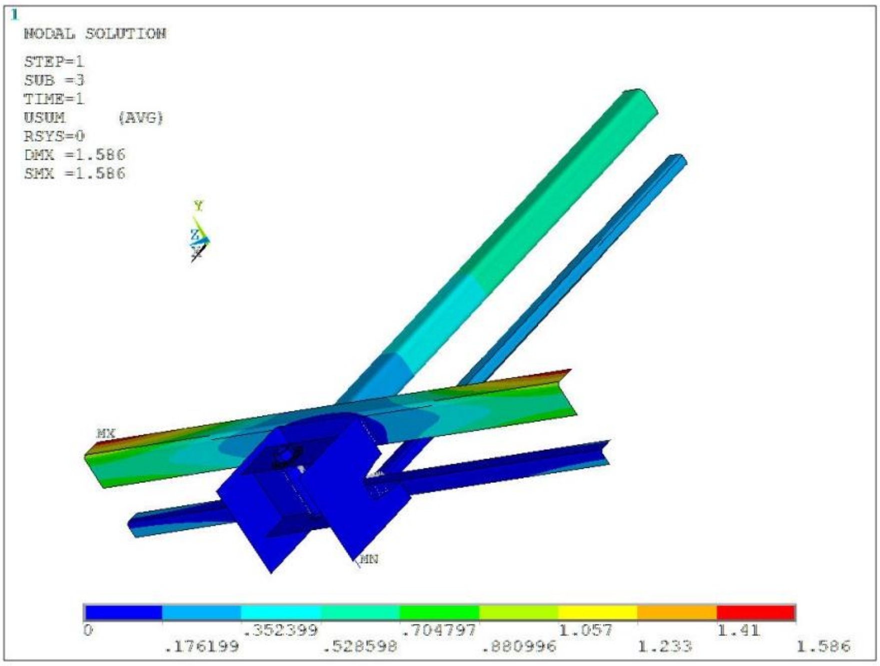


Appendix 15 figure 9. The vector sum deformation distribution

Appendix 15 table 6: Deflection values of the calculation model 1

Node	Deflection Y-axis [mm]	Component	Acceptable deflection [mm]
Max	-1.599	Upper roller track	-
4238	-0.64898	Upper cross beam	2.21
9202	-0.62287	Upper roller track	1.33
9362	-0.62477	Upper roller track	1.33

Stiffness of the structure, Calculation model 2

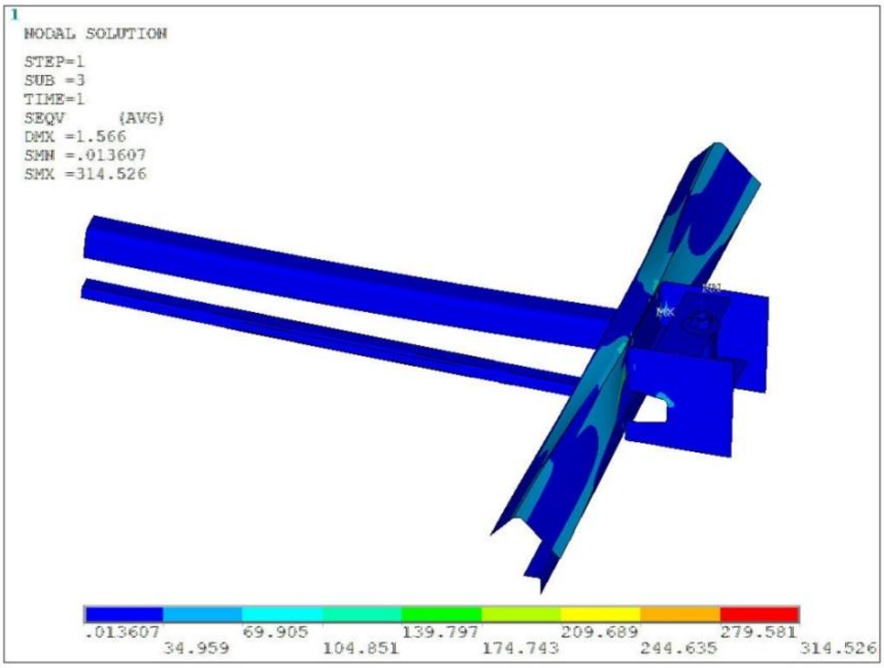


Appendix 15 figure 10.The vector sum deformation distribution

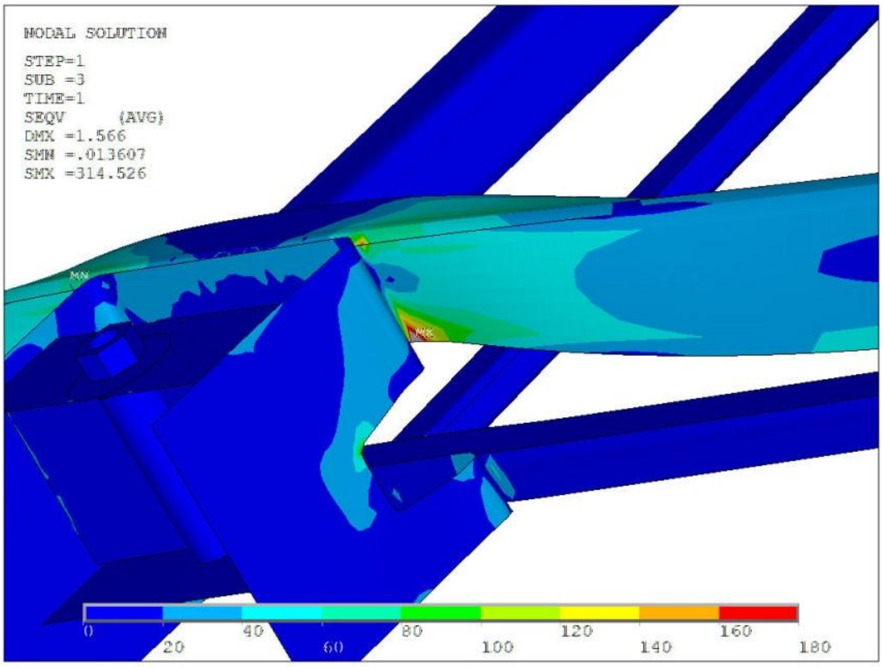
Appendix 15 table 7: Deflection values of the calculation model 2

Node	Deflection Y-axis [mm]	Component	Acceptable deflection [mm]
Max	-1.586	Upper roller track	-
4238	-0.70078	Upper cross beam	2.21
9202	-0.63971	Upper roller track	1.33
9362	-0.64151	Upper roller track	1.33

Strength of the structure, Calculation model 1



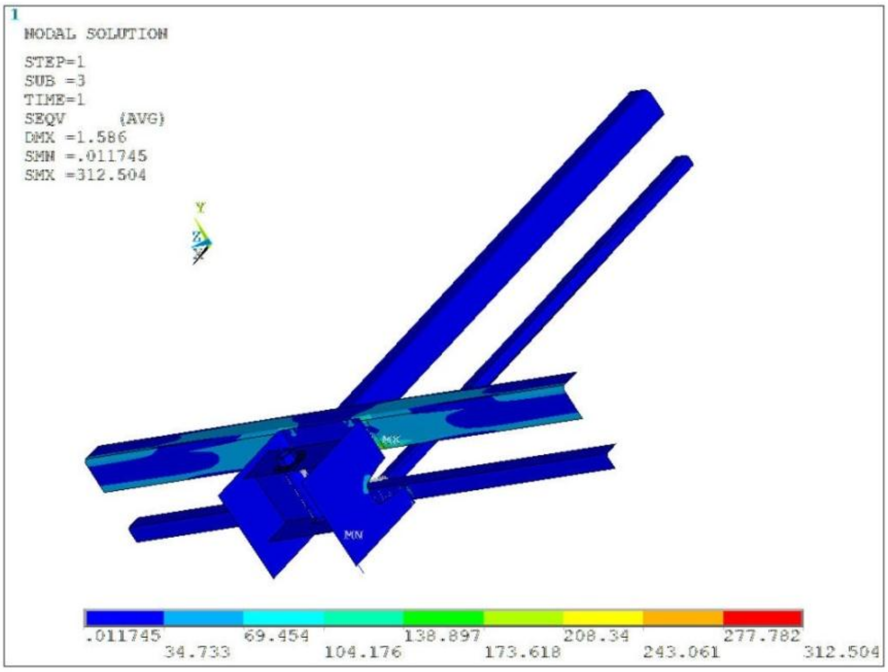
Appendix 15 figure 11. Von Mises stress distribution



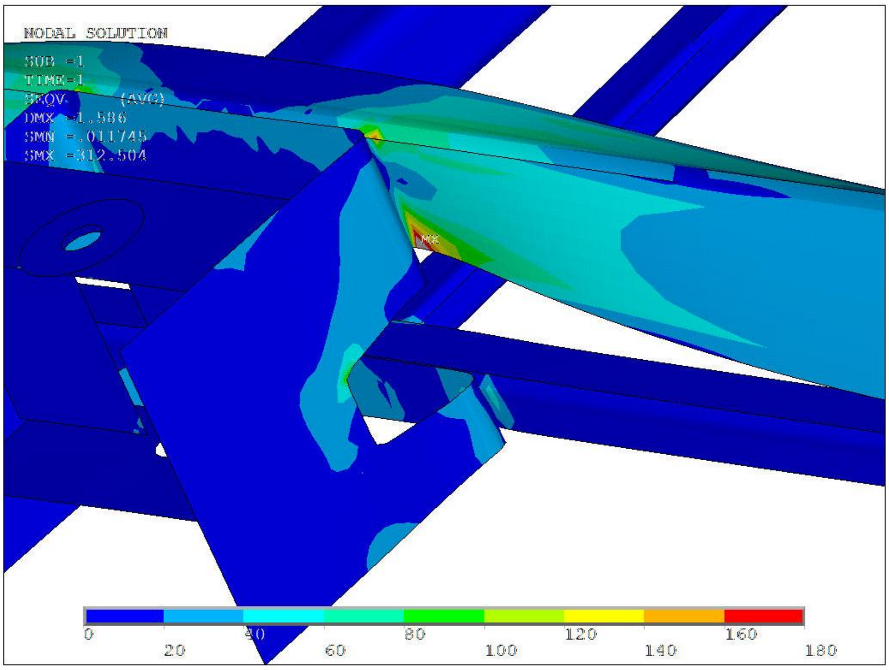
Appendix 15 figure 12. Von Mises stress distribution

The highest stress is 314.5 MPa. The stress peak can be ignored as a singularity point as the peak occurs inside of 2 elements. The principal stress in the peak is compression and is not happening in reality as the components are not bonded like in the model. Stresses over all are below 180 MPa.

Strength of the structure, Calculation model 2



Appendix 15 figure 13. Von Mises stress distribution



Appendix 15 figure 14. Von Mises stress distribution

The highest stress is 312.5 MPa. The stress peak can be ignored as a singularity point as the peak occurs inside of 2 elements. The principal stress in the peak is compression and is not happening in reality as the components are not bonded like in the model. Stresses over all are below 180 MPa.

CONCLUSION

- The structure meets the requirements of the clause 5.2.5.
- The maximum deflections in support beams are under the limit of l/ 750
- Maximum stress is over 300 MPa in both cases but this can be ignored as a singularity point
    - Generally stresses are less than 180 MPa

LESSONS LEARNED

The flange of the roller track profile is deflecting more than the acceptable limit but the actual waist of the track is not. In reality the roller track profile has to carry only passenger load which is equal to the required brake load in EN 115-1. Therefore the deflection of the roller track can be considered to be acceptable.

True deflection of the flange in use can be calculated by using the brake load. However based on the results in this report and original design of InnoTrack™ middle section it can be said that the rigidity of the flange is enough.

DEVELOPMENT ACTIONS

Develop the connection between two middle sections and head sections to be compatible with the angle profile.

USED SYSTEMS

Appendix 15 table 8: Used systems

Software	Version	Description
PRO Engineer	Wildfire 4.0	3D CAD
ANSYS	Mechanicals V12.1	Finite element analysis