MAINTENANCE CONSIDERATION IN SPECIAL ELEVATOR CAR ENGINEERING
AND
CONCEPT DESIGN FOR FIXING OF HEAVY LOWERED CEILINGS

HAMK
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Hiep Hoang Nguyen

HAMK
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ABSTRACT

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Author Hiep Hoang Nguyen **Year** 2014

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ABSTRACT

The thesis objectives comprise of two major parts; one is to present design guidelines for friendlier maintenance in elevator cars, the other is to introduce concept designs of fixing mechanism of the lowered ceiling in special elevator car. KONE Industrial Ltd. is the commissioning organization of the dissertation. The obtained results are expected to improve maintainability in the design of the elevator car; on the other hand, new fixing solutions of the ceiling can meet requirements of reliability, safety as well as maintainability.

In the first part, personnel from different departments within the company were involved in meetings and interviews for collecting recorded issues related to elevator car engineering and design. The collection of the difficulties from multiple perspectives will form the categorized guidelines with specifications and demands. In addition, the student studied and introduced a general approach to design for maintainability in product design and development as the theory background of designing of mechanical components in elevator technology.

Based on the results of the first part, the second part presented fixing solutions for the elevator ceiling that can qualify the restrictions of operational space and high demand in reliability, safety and maintainability. In this section, various approaches and methodologies were applied to establish and develop the fixing mechanisms. For consulting and assessing, meetings among student and supervisor at HAMK and KONE counterparts were conducted during the idea creation process as well as design study and elaboration. In addition, factory visits did play an important part of facilitating the student familiarizing and understanding of the work.

Keywords Maintenance, elevator car, fixing mechanism, concept design
Pages 45 p. + appendices 19 p.

CONTENTS

1 INTRODUCTION

Urbanization and taller skyscrapers are the unmistakable driving forces for elevator industry. In addition, higher demand for sustainable products and solutions make the elevator engineering and design even more sophisticated. In the same context, less energy consumption requires minimum moving mass that lead to the demand of lighter car structure, less material usage and better design. The thesis work is to understand the result of such contemporary issue.

Maintenance in product life cycle and design for maintainability are taken into consideration with the result of specific guidelines and dimensions. Moreover, maintenance issues in KONE customized elevator car are collected for the first time to formulate the engineering instruction that can particularize the requirements for car components designing.

Conceptual design of elevator ceiling fixing mechanism is implemented as the result of rational procedures starting from hand sketch to 3D modelling detail design and study. Finite element analysis using PTC Pro|Enigneer is executed base on the study of applicable mechanical component failure theory.

2 PART 1: MAINTENANCE CONSIDERATION IN PRODUCT DESIGN AND KONE'S ELEVATOR CAR

In part 1 of the dissertation, maintenance is taken into account from various perspective and scale starting from its role in a product life cycle to maintenance operations in elevator business. On the hand, KONE products in particular still remain the major target.

2.1 Maintenance in product life cycle

Product life cycle management, in essence, can be considered as an act of balancing among customer satisfactions, corporate profits and environmental friendliness. Considered as an essential mean, maintenance, in its nature, is the most efficient way to preserve conditions of a product that its functional level is above the level required from the customer. Nowadays, maintenance operations include upgrade or modernization due to changes in customer needs, or naturally, deterioration. In this context, maintenance not only minimizes material consumption and environmental impact, but also maintains appropriate incomes.

Throughout the life cycle of a product, as mentioned, there are changes from customer requirements or product conditions. These alternations form gaps between designed function and realized function that illustrated in *figure 1*:

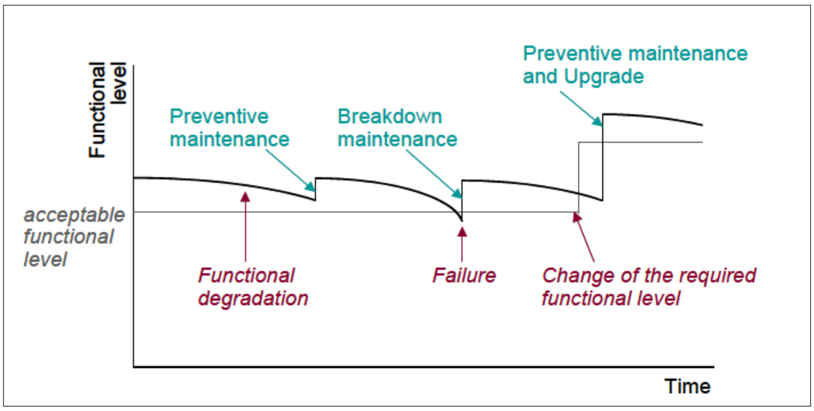


Figure 1 Maintenance activities (Seliger, 2007)

As from the graph, performances of maintenance will fill such gaps. And in order to achieve the mission, there are activities that should be included in a maintenance operation:

- Design for maintainability: in product design and development phase, maintainability is evaluated then a design data for maintenance strategy planning and task controlling can be introduced
- Maintenance assessing and improving: evaluation of results of maintenance operations is carried out to improve maintenance strategy or task control.
- Dismantling planning and execution: at the end of a product life cycle, its dismantling and disposal need to be well planned and executed.

2.2 Design for maintainability in product design and development

2.2.1 Maintainability in engineering design

In engineering design, maintainability is the ability of the product or system that can be maintained to restore to or retain in a specified condition within a given period, through a scheduled or unscheduled maintenance that is performed in accordance with prescribed procedures by specialised personnel and resources. Maintainability, in this context, should be considered as an integral part and a fundamental design parameter from the earliest phase of product design and life cycle engineering.

As an aspect of maintenance, maintainability comprises spare parts provisioning, and in many cases, risk analysis. Maintainability takes into consideration the downtime that is a given time within which system can be restored to an operational efficient condition. Therefore, maintainability also reflects serviceability, supportability and cost-effectiveness.

The correlation between a system value and its maintainability can be illustrated in the following graph:

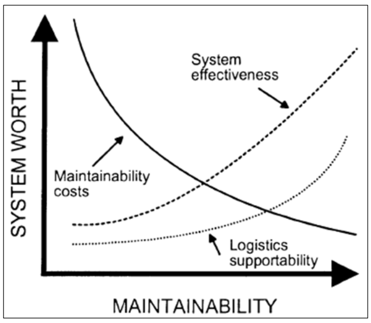


Figure 2 System worth versus maintainability (Peters, 1994)

A system worth is the function of purchase price, operational cost, maintenance cost and its value add. System effectiveness will increase sharply when its maintainability is higher. On the other hand, system worth is still very high when maintainability cost is significant as a result of low maintainability of the system.

2.2.2 Design for maintainability

Design for maintainability is the design work that meets the requirements of visibility, accessibility, testability, reparability, and inter-changeability. As applied to a system level, the act of design for maintainability contains the assessment of the expected performance in terms of computing the relation between system performance capacity and its downtime.

The ultimate goal of design for maintainability is maintenance to be performed safely and efficiently. The other objectives of designing for maintainability include:

- To minimize the usage of specialized skills, tools and training
- To minimize time spent for maintenance activities
- To ensure personnel safety.

How equipment and systems are maintained is fundamentally affected by their design and construction in the matter of complexity, duration, frequency and safety. Thus, set of elaborative guidance and requirements are essential for designers in order to facilitate maintainability and establish risk-free maintenance activities simultaneously.

The preliminary rules for maintenance:

- Maintenance procedure is compatible with system's functional, operational and safety constraints.
- Maintenance and repair work is executed only when the system is shut down and will not be started unintentionally.
- Maintainability of a system is improved significantly when:
  - Reliability is enhanced
  - Number of components is minimized
  - Logical layout and organization of components is implemented
- Troubleshooting guides and tools list to be distributed to maintenance personnel

The following tables are detail guidelines for design for maintainability:

Table 1 Design guidelines

Category	Description
General	Identify reliability, installation types and arrangements of components so that difficult to maintain parts will be made more reliable.
	Simplify system's structure and architecture.
	Use standard interchangeable components wherever possible
	Design for minimum adjusting or degradation requirement
	Allocate handle or handholds on heavy parts for safe handling
	In access panels or doors, minimize the number of removable fasteners (screws, bolts, nuts, etc.)
	Capacity and reliability of replaceable or re-serviceable items (filter, screen, battery power supplies, bulbs, etc.) will be higher than the minimum system's functional requirements.
	Maintenance requiring special skills or tools shall be minimized.
	Maintenance information and data to be distributed (maintenance schedule, history and checklists)
Accessibility	Components, which are either most critical to system operation or require frequent maintenance will be most accessible.
	Structural components shall not block the access to or removal of the component
	Detail access dimensions are shown in *table 2*
	Cables and wires shall be routed to be accessible for inspection and repair.
	Access hatch covers and doors will open through 180 degree and be self-supporting in the open position
Visibility	Maintenance point, where hand and arm are manipulating components, tools and fasteners, will be visible.
	Labeling:

	- Improve readouts, indicators to reduce human decision-making circumstances. - Provide warning labels for hot, heavy components, or the ones that store mechanical or electrical energy - Allow positive identification to the cables, fluid lines, and shields protecting other subsystems
Others	Component-machine interface: - Component can only be installed correctly - The component will be supported by mounting pins or other devices while being bolted or unbolted.
	Refine fault isolation design solution: Nominate testing procedures or test points to be provided.
	Offer operational interlock that only allows system or subsystems to be activated when they are installed correctly.

Table 2 Opening dimensions for single hand access with tools (American Bureau of Shipping, 2013, pp. 62-64)

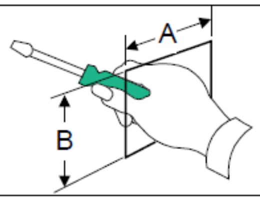
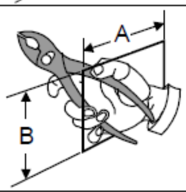
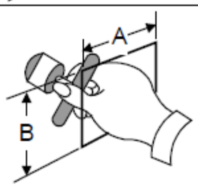
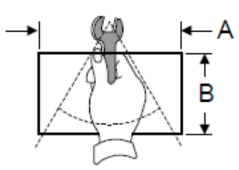
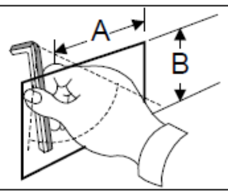
Description of Opening		*Minimum Dimensions mm (in.)*		*Task Description*
		A	*B*	
	Bare Hand	110 (4.25)	120 (4.75)	Using common screwdriver, test probe etc., with freedom to turn hand through 180°
	Gloved	165 (6.5)	180 (7.0)	
	Bare Hand	125 (5.0)	115 (4.5)	Using pliers and similar tools
	Gloved	175 (7.25)	200 (7.75)	
	Bare Hand	150 (6.0)	150 (6.0)	Using "T" handle wrench, with freedom to turn hand through 180°
	Gloved	190 (7.5)	210 (8.25)	
	Bare Hand	275 (11)	200 (8.0)	Using open-end wrench, with freedom to turn wrench through 60°
	Gloved	325 (12.75)	260 (10.25)	
	Bare Hand	120 (4.75)	150 (6.0)	Using Allen-type wrench, with freedom to turn wrench through 60°
	Gloved	175 (7.0)	200 (8.0)	

Table 3 Opening dimensions for single hand access without tools (American Bureau of Shipping, 2013, pp. 62-64)

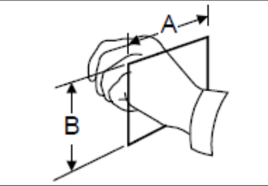
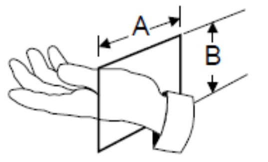
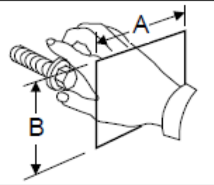
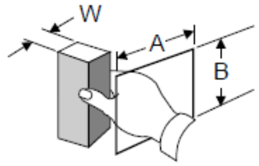
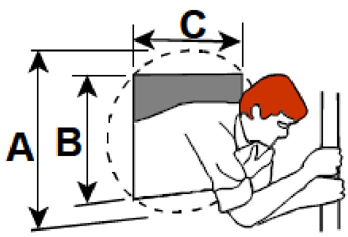
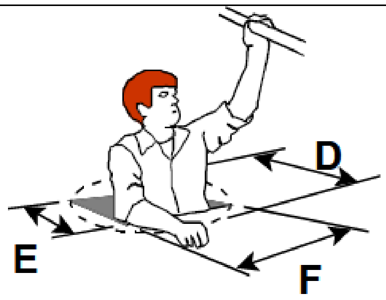
Description of Opening		*Minimum Dimensions mm (in.)*		*Task Description*
		A	*B*	
	Bare Hand	125 (5.0)	100 (3.75)	Empty hand Clenched fist extended to wrist
	Gloved	150 (6.0)	115 (4.5)	
	Bare Hand	100 (4.0)	60 (2.25)	Empty hand Hand flat extended to wrist
	Gloved	150 (6.0)	100 (4.0)	
	Bare Hand	115 (4.5)	120 (4.75)	Grasping small objects (up to 50 mm (2 in.) or more wide) with one hand
	Gloved	170 (6.75)	175 (7.0)	
	Bare Hand	W+45 (W+1.75)	125 (5.0*)	Grasping large objects, 50 mm (2 in.) or more wide with one hand
	Gloved	W+100 (W+4.0)	175 (7.0)	

Table 4 Hatch shapes and dimensions (American Bureau of Shipping, 2013, pp. 62-64)





Access – Shape and Dimension	*Minimum*
Side Access	
Round – A	685 mm (27 in.)
Square	660 mm (26 in.)
Rectangle – B	660 mm (26 in.)
– C	760 mm (30 in.)
Top or Bottom Access	
Round – D	635 mm (25 in.)
Square	580 mm (23 in.)
Rectangle – E	330 mm (13 in.)
– F	610 mm (24 in.)

2.3 Maintenance in elevator industry

In the entire plant or building, elevator is among the most sophisticated and specialized system. It comprises wearing components, assemblies of mechanical, electrical and in some cases hydraulics subsystems that are distributed at various levels from the basement to roof. In modern elevator operation, moreover, component becomes more complex as automation plays a more important role and that makes maintenance responsibility weightier and even more difficult. Therefore, elevator should be designed for ease of installation and maintenance as an integrated part of the building system. In *figure 3*, general KONE elevator component names and their locations are illustrated.

[Figure removed from public version]

Figure 3 Sample of KONE elevator components (KONE)

To ensure the elevator system operates safely and efficiently, a primary preventive maintenance program is planned for each installation and distinctive set of objectives should be reached:

- Maintaining safety: protective equipment and components such as levelling controls at elevator entrances, elevator doors that highly interacted by users should be well-maintained. In addition, throughout the system, there are various automatic safety devices that guard against unexpected hazards and failures must always be in full readiness to operate instantly, reliably in any situation.
- Apart from ensuring the system operates safely and efficiently via preventive maintenance, periodic inspection and testing conducted by manufacturer will also be included to make sure the devices comply with applicable safety codes.
- Economy of maintenance: Due to its highly interrelated structure, detecting and replacing of weary components during preventive maintenance will keep the elevator system from costly emergency repairs or system down-time costs.

A typical elevator maintenance or inspection work includes:

- Mechanical components and equipment to be intact and properly fastened (such as sheaves, buffers, limit switches and door components)
- Hoisting mechanics and ropes to be checked for weariness, lubrication, vibration and mounting
- Guide rails to ensure alignment and fastening of among rails, brackets, and fish plates
- Observation operational conditions of communicators, brushes in the machine room
- Other electrical equipment and safety devices are also included such as emergency brakes, over speed governor.

2.4 Design guidelines for maintainability in KONE elevator car

2.4.1 Information collecting

There was a highly interactive course of action carried out during the work. Many kinds of internal documents were given and viewed (such as installation manuals, product descriptions, safety codes, etc.). Discussions, interviews, and meetings with members from different car engineering teams were arranged frequently and flexibly. Factory visits, as a matter of fact, were very helpful.

For internal usage, the collected issues were delivered in a separate document follows KONE format.

2.4.2 The design guidelines

Table 5 Design guideline for maintainability in KONE elevator car

[Table removed from public version]

3 PART 2: CONCEPT DESIGN FOR FIXING OF HEAVY LOWERED CEILINGS

Considered as the major proportion of the dissertation, the concept design of the fixing mechanism required various approaches, skills and knowledge. The flow chart in *figure 4* illustrates the processes and events that were performed and took place.

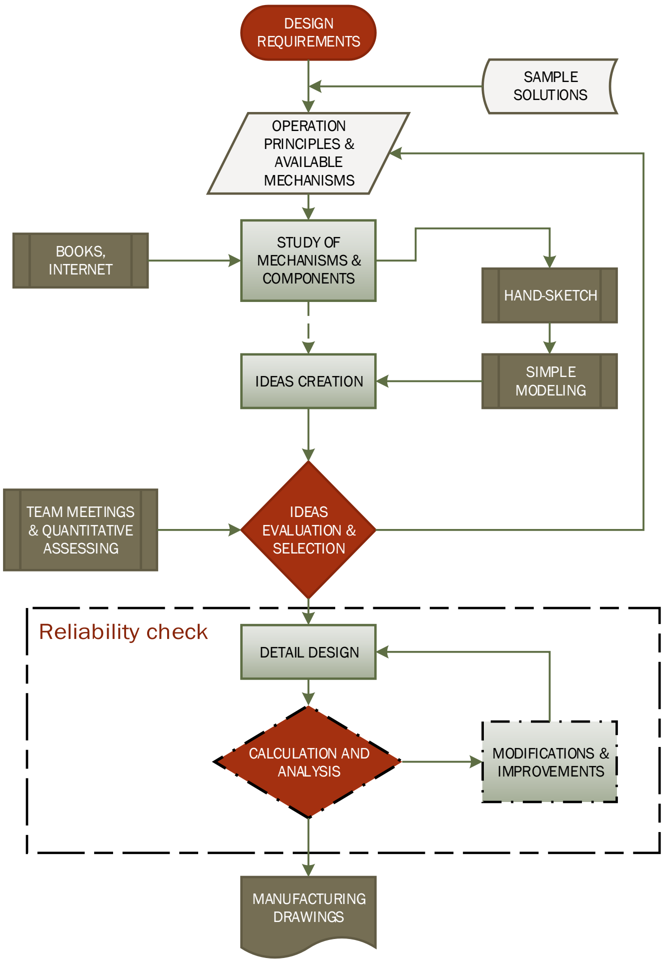


Figure 4 The thesis concept design flow chart

In the whole process, it can be noticed that there are operations that require extra attention in term of reliability and safety. Since the concept ideas and detail design were executed as well as the student could offer, the calculation and analysis, on the other hand, might require certain level of proficiency and academic background that the student could not be qualified for.

3.1 Recorded issues in ceiling and design requirements

In highly customized elevator car, ceilings were designed in many forms and shapes using different type of materials. Furthermore, carrying and interacting with passengers make safety and aesthetic requirements of the interior of the car are very high. The elevator car ceiling is subjected to such prerequisites.

As a result, ceiling fixing mechanisms should be reliable, intuitive and easy to operate for one man for maintenance service. The ceiling is able to be opened from inside the car and from the roof.

In addition, other requirements that the design must fulfil are:

1) Components included in design:
   - Locking components
   - Hinging components
   - Safety components that will engage in case of failure of locking mechanism (i.e. security rope)
   - Interface for brake winch
   - Stiffener for heavy ceilings
   - Fixing interface to the car roof
2) Technical specifications:
   - Ceiling height 70 ≤ H ≤ 200 mm, minimum gap between ceiling and car wall: 15mm
   - Maximum weight of in part of suspended ceiling, m=100kg
   - Car ceiling to be opened up to 90 degree
   - Four suspension points can be used to stabilize heavy ceiling, 2 for hinging, 2 for locking
   - Adjustability for assembly, i.e. slots will be used instead of holes

3.2 Process and creation of fixing mechanism concepts

3.2.1 Methodology and approach

Starting with the existing solutions, student was advised to familiarised himself with mechanisms that already works. Many technical documents were also reviewed to broaden the view.

In the next step, handbooks and sourcebooks of mechanical components and mechanisms are taken as references to the base of idea creation. Furthermore, ready-made and commercial solutions of the surrounding products were targeted as well as online researches.

Then, working principles and range of potential mechanisms and components were drafted. Based on that, hand-sketches of the ideas were created.

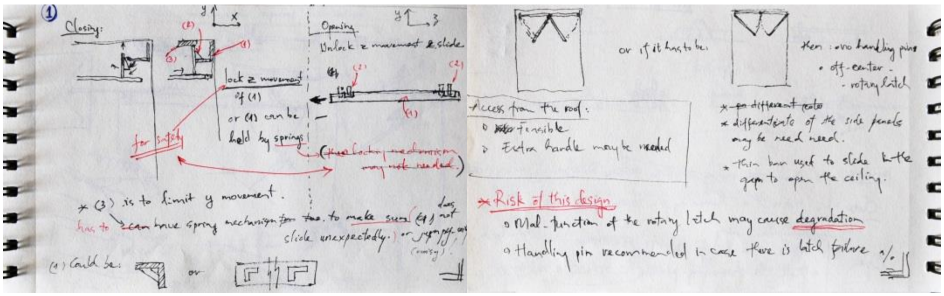


Figure 5 Draft of working principles and assessment

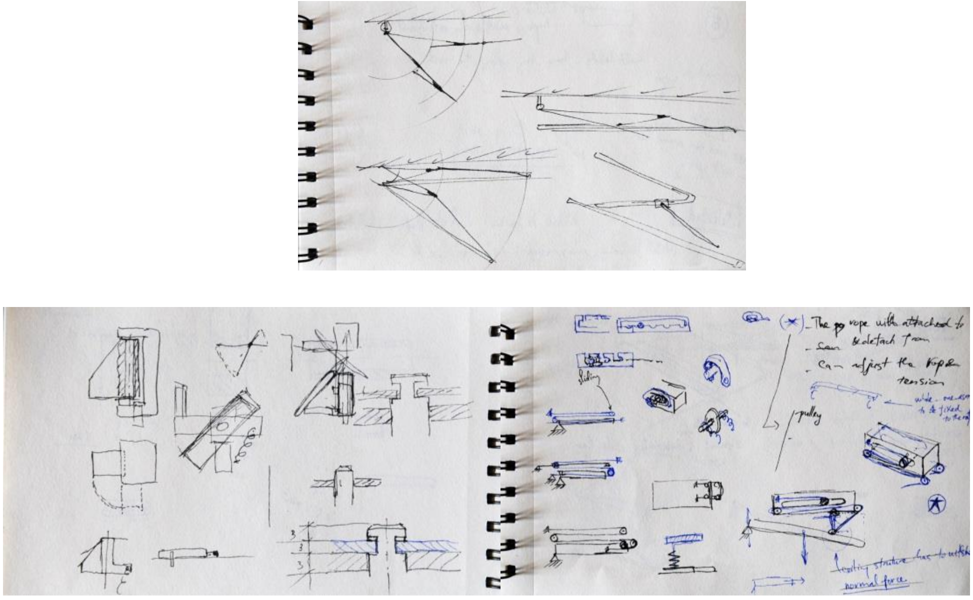


Figure 6 Ideas hand-sketches

3.2.2 The fixing mechanism concept ideas

Consequently, 3D models were generated to solidify the sketches and this process of modelling based on hand sketch is iterated for each idea creation.

a) Idea 1: the sliding bar

- Properties: This idea uses a cut bar to lock and unlock the latch by sliding. There are customized latch component and spring included.

  The idea is simple in principle, however, it can comprise many components and its reliability needs to be checked, especially the latch. Moreover, the deflection of the bar should be taken into careful consideration when the ceiling panel is very wide.
- Concept: Located one the elevator car roof will the bar and its supports. On the ceiling panel, latch component is fixed.

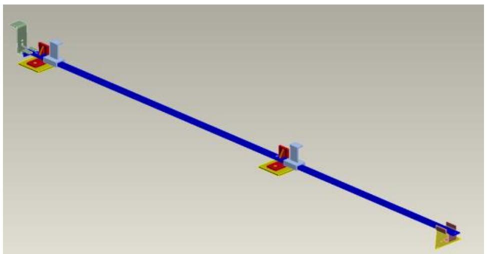


Figure 7 Idea 1 assembly

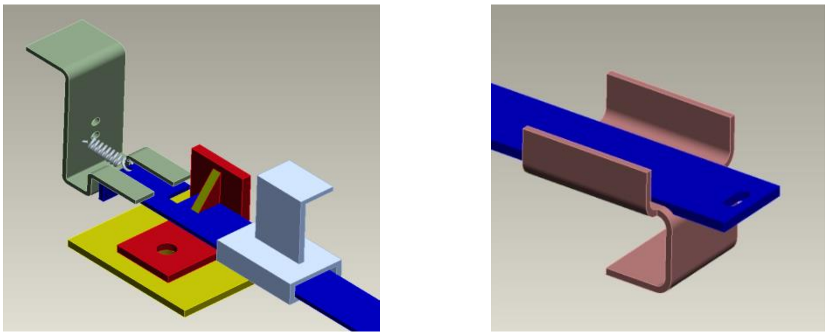


Figure 8 Idea 1 components

b) Idea 2: rotary latch

- Properties: A commercial rotary latch is customized for easier operations in confined space. Two phases of locking and opening principle guarantee the reliability. An stiffener is used to improve rigidity
  This idea requires a relative expensive component and raises concern about applicability in heavy ceiling structures.
- Concept: Stiffener, the pin(s) and a secondary locking mechanism are fastened to the ceiling panel. The rotary latch and control plate are fixed on the roof. The yellow plate is used to release the ceiling while the brown handle acts as a secondary lock.

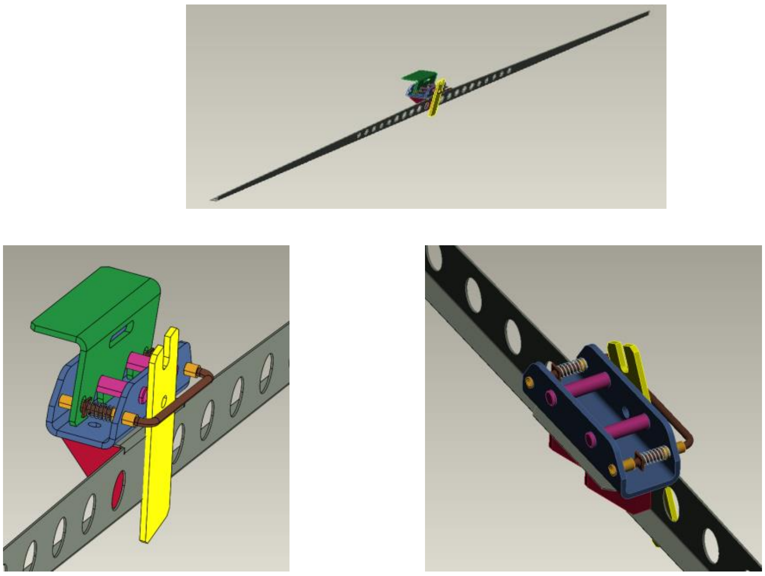


Figure 9 Idea 2 overview and its components

c) Idea 3: combination of gas spring and linkage

- Properties: opening and closing movement of the ceiling are converted to sliding of a pin, which is connected to a gas spring by a lever. Locking or releasing that lever allows the ceiling is locked or unlocked.
  The idea is not appreciated due to its asymmetric locking mechanism and the lever's rotation needs a large space, beside, gas spring component requires maintenance activity.

- Concept: The movement was formed and simulated in an open source software name Linkage. On the ceiling, there are levers located on both sides of the ceiling panel. A gas spring and sliding mechanism are located on the roof.

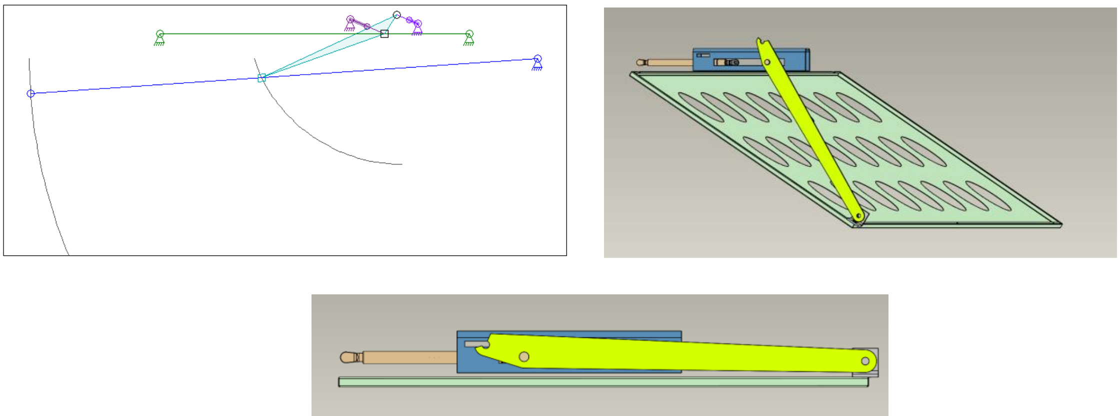


Figure 10 Idea 4 working principle and overview

d) Idea 4: Sliding latch

- Properties: A pair of rods will push 2 bar acting like latches when the ceiling panel rotates to its lock position.
  Sliding of a plate in fixing mechanism located on the car roof will handle the locking.
- Concept: This idea is another version of the first one with the latching mechanism based on the ceiling's rotation.

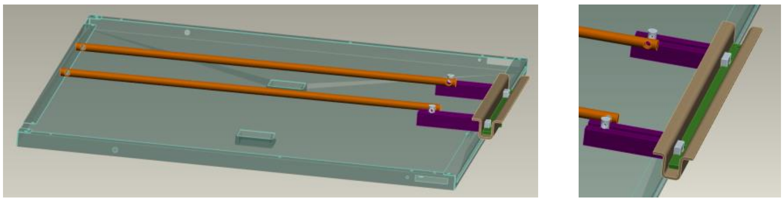
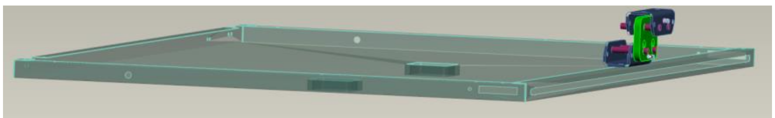


Figure 11 Idea 4 models

e) Idea 5: the hanging plate

- Properties: Two versions of a pins assembly are located on the ceiling panel and the car roof. By sliding the lock plate, 2 pins on the ceiling are fixed and there is a extras wing nut to lock that plate from sliding
  This idea is simple and reliable. However, according to colleagues' comments, operation principle is not intuitive and maintenance friendly.
- Concept: the ceiling is locked and unlock by sliding the green plate in *figure 12*. There is a wing nut which will lock the plate in position.



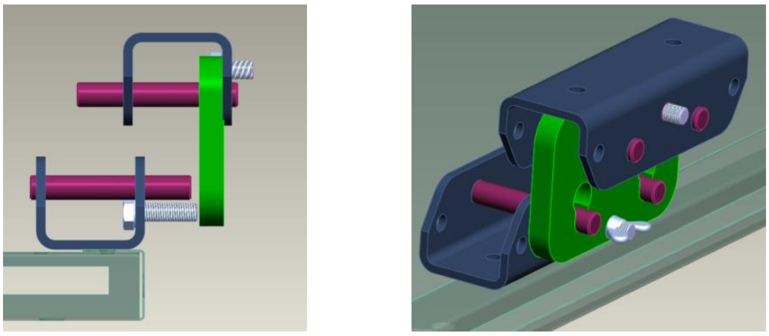


Figure 12 Idea 5 overview and components

f) Idea 6: Corner fixing

- Properties: locking mechanisms are located at the corners of the ceiling panel. The design consists of 3 components as shown in *figure 13*, they are 2 bent plates and a rod.
  The design is compact and fixing mechanism offers rigidity. But it is neither easy to use nor reliable due to their separation in location and requirement of simultaneous operation.
- Concept: The rod is able to sliding along the guide cut in yellow plate that fixed to the roof. By sliding the rod to locking area when the blue plate on ceiling is in position, the ceiling is locked. Reverse the action chain to release the ceiling.

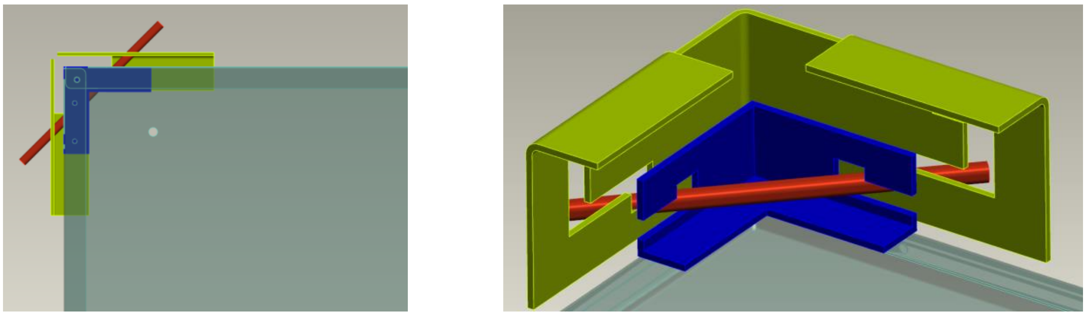
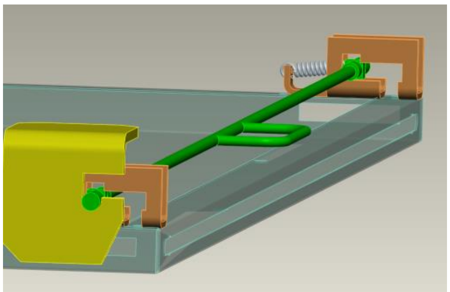


Figure 13 Corner fixing assembly

g) Idea 7: Sliding rod

- Properties: The idea comprises of a simple bent plate fastened to the roof and an assembly of a rod which acts as a latch. There is a handle in the middle where locking and releasing action will happen.
  There are raised question about the stiffness of the rod in action and the similarity in design of the yellow plate to the existing solutions may lead to the same contemporary issues
- Concept: By pulling and pushing the rod, the ceiling is locked or released. The U profiles are supports of the rod and springs are used to make sure the rod stay in position.



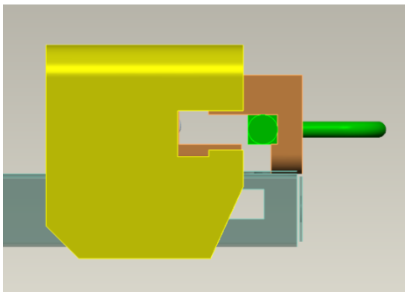
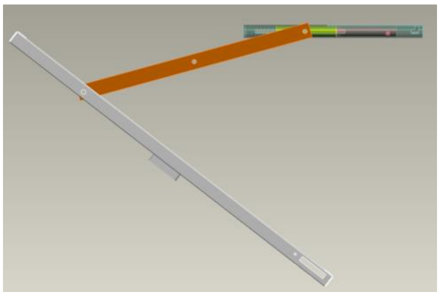


Figure 14 Idea 7 overview

h) Idea 8: Rotate-to-lock component

- Properties: There is a locking assembly located on the roof that the sliding movement can be locked by rotating a pin. The ceiling is connected to the device via a lever.
  The idea reveals its drawbacks clearly when a heavy ceiling comes to usage. Stability, reliability is questioned due to high stress concentration and lack of connection points
- Concept: at closing position, the lever will push the rod to the accessible area where the movement of the ceiling will be locked and unlocked.



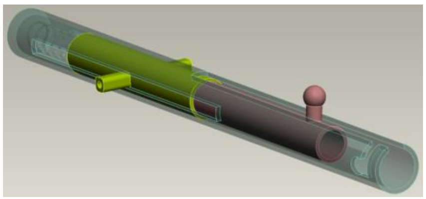


Figure 15 Idea 8 overview and its component

i) Hinge designs

- Properties: In an attempt to improve the existing hinge performance in terms of rigidity and stress endurance, hinge plates were thickened and bent so that their stiffness will be increased. Two variants of this approach were created. However, they are discovered to be unqualified in the later phase.

Figure 16 Hinge designs

j) Ceiling fixing profile

- Properties: the ceiling fixing profile is used as an interface for the ceiling fixing mechanism to the car roof. It was designed follow the standard solution. Specific dimensions should be given in each case.

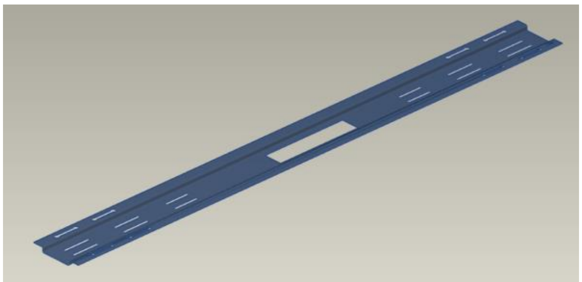


Figure 17 Ceiling fixing profile

k) Latch designs

At the later phase of the detail design stage, several ideas for the latch assembly were formed in order to facilitate the reliability of the locking mechanism. As shown in *figure 18*, vertical or horizontal rotation or the latch bar using either torsional or compression spring were put into consideration. However, they were gradually eliminated when the design requirements are applied.

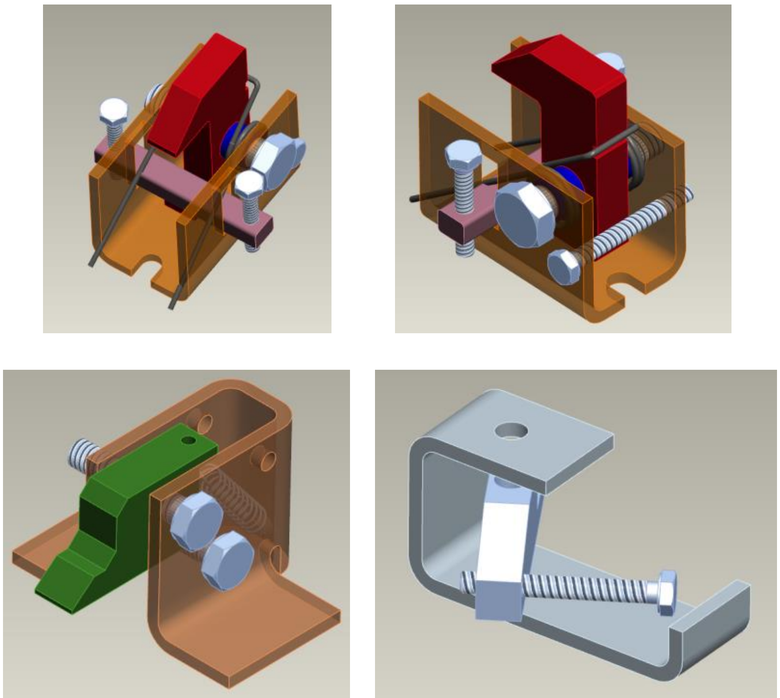


Figure 18 Designs of latch

3.3 Selection of concept and detailed designs

The next step of the conceptual design for the ceiling fixing mechanism is to have one best idea selected and elaborated so that it can be ready for manufacturing and testing.

3.3.1 Selection of concept

In order to make a decision on which concept would be selected, a quantitative evaluation of the ideas has been performed and shown in *Table 6* bases on the ceiling design requirements and their importance rate. There were some ideas, which were created at the later phases of the process or unqualified, were not evaluated.

Table 6 Selection of concepts

Evaluation criteria	Importance rating (5)	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 7	Others
simplicity of design (amount of component)	3	2	2	-	4	2	3	2	-
ease of operation (one man operation)	4	4	1	-	4	1	4	1	-
locking reliability (correctly-fixed-only)	5	4	4	-	3	4	3	2	-
heavy weight support	4	3	4	-	4	3	3	3	-
car roof access and operation	2	3	2	-	4	1	3	2	-
free space requirement (10mm)	4	3	2	-	4	1	2	2	-
	TOTAL SCORE Sum of products of criteria value and impo. rate)	*72*	*58*	*0*	*83*	*48*	*66*	*44*	

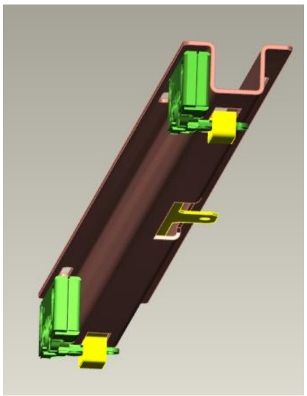
Base on the obtained total scores, idea number 4, at the scores of 83 was selected to develop into detail.

3.3.2 Detailed designs

In this phase, every component was carefully dimensioned and shaped to comply with the design constraints. In addition, as much as the student was aware of, engineering factors of design such as design for manufacturing, design for assembly also were taken into account. Nevertheless, there were compromises that resulted in asymmetric or complex components structure.

3.3.2.1. Rotary latch

In this concept, commercial rotary latches were applied to increase reliability and safety of the locking mechanism. A bent plate centralized the opening and closing of the ceiling. The roof fixing profile, in the same manner, has been modelled in 2 shapes; the L profile requires welded stiffeners while the U one does not.



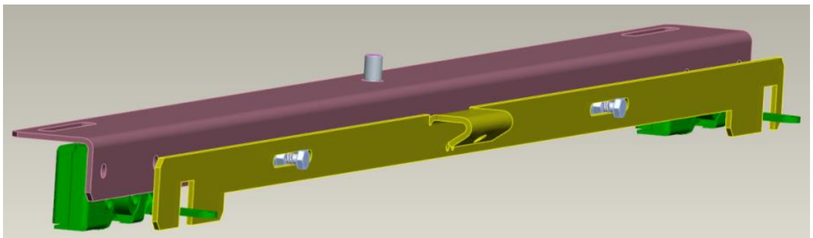


Figure 19 Variations of rotary latch concepts

Fixing of security ropes was taken into consideration in this concept as well. There will be an eye bolt fastened to the roof; it will hang the rope whose ends are attached to the pins on the ceiling as shown in *figure 20.*

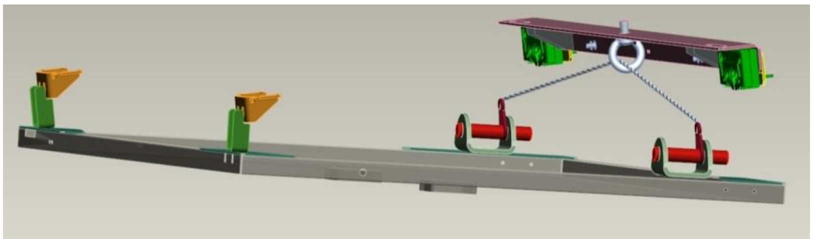


Figure 20 Fixing of security rope

3.3.2.2. Sliding rod

The concept is a developed version of idea 7. Reliability of the working principle is improved significantly. However, the idea was not favourable because of the locking mechanism using the bent plate. Concept: The ceiling is unlocked by sliding the bolts located in the middle, the springs will keep the rod in locking position when the bolts released.

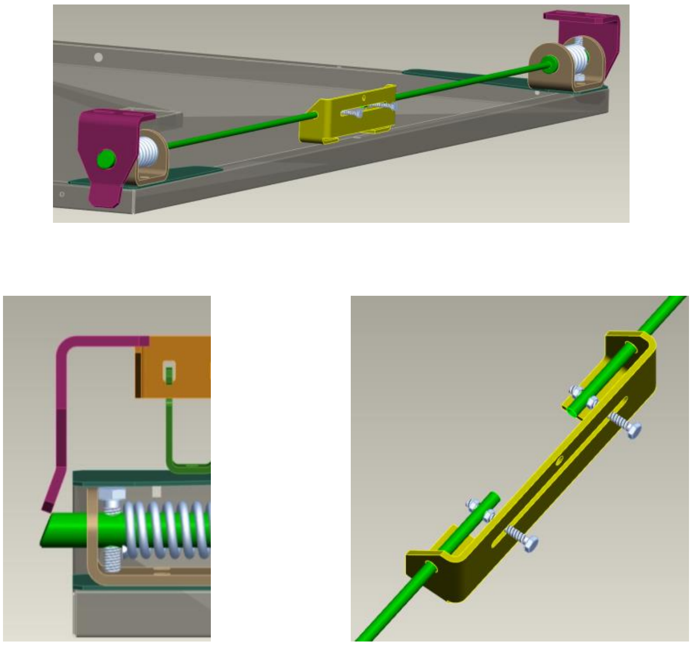


Figure 21 Enhanced sliding rod concept design

3.3.2.3. Tee lock

A Tee plate fixed to the roof will be locked by a slidable C profile assembled on the car rood (see *figure 22*). Spring forces are constantly applied to the profile and control by a centralized bent profile. The idea was not yet fully reviewed and assessed. However, it can be noticed that this concept is reasonably reliable and space saving.

Operation:

Ceiling closing: Centralized bent plate will unleash the C profile to lock the Tee plate when it is pushed by the bolt on the ceiling indicating that the Tee plate is at locking position.

Ceiling opening: by sliding the bolts towards the centre, the ceiling is unlocked and starts to open; simultaneously, the bent plate is lowered to lock the bolts that keep the C profile at open and ready for the next closing operation.

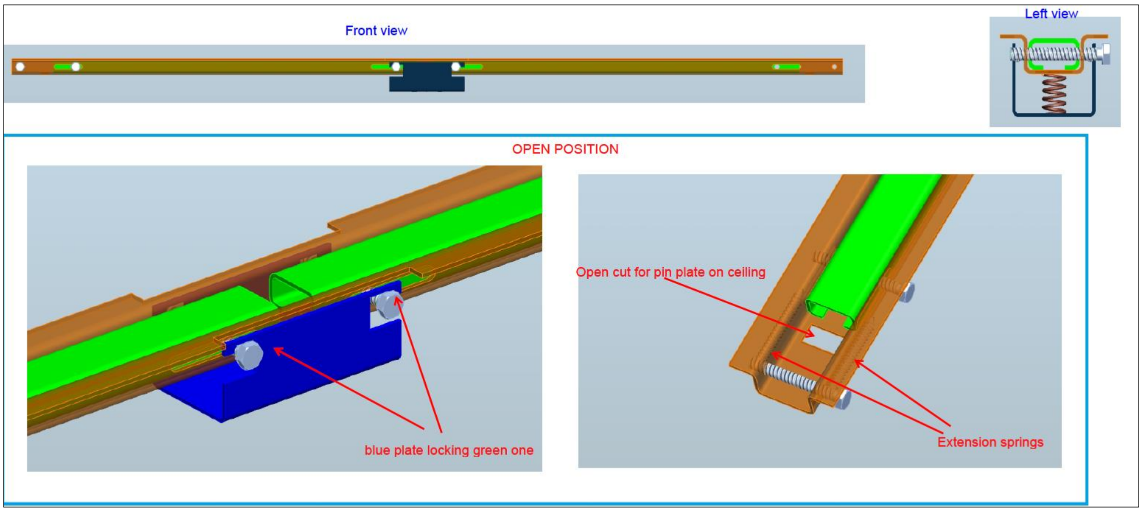


Figure 22 Tee lock concept overview and components

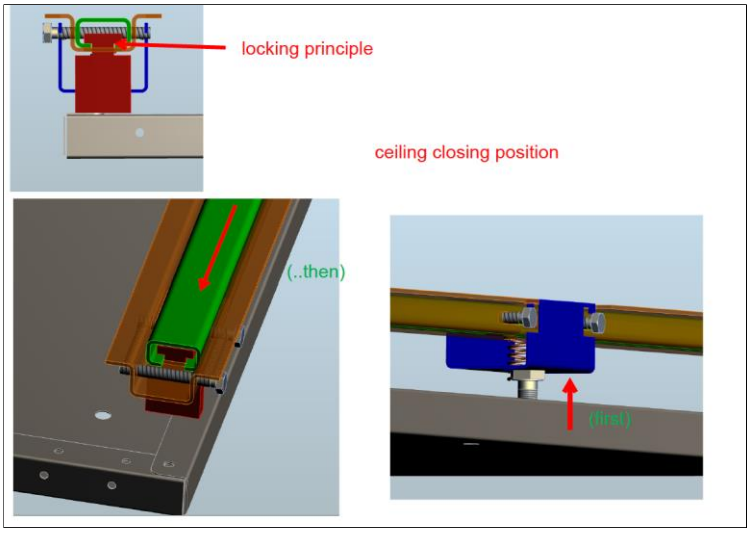


Figure 23 Operation sequence

There was another concept, which became the selected one, will be described in the following section.

3.4 Concept design and study

The next steps in the process comprise the concept detail design, calculation and analysis of components that might lead to changes and modifications. Introductory level of related theory also will be included as the foundation of the design study.

3.4.1 Concept design

The axonometric view with balloon for components in *figure 24* presents the selected concept of the ceiling fixing mechanisms. Flow of thinking and formation of the concept will be mention in the description of each component.

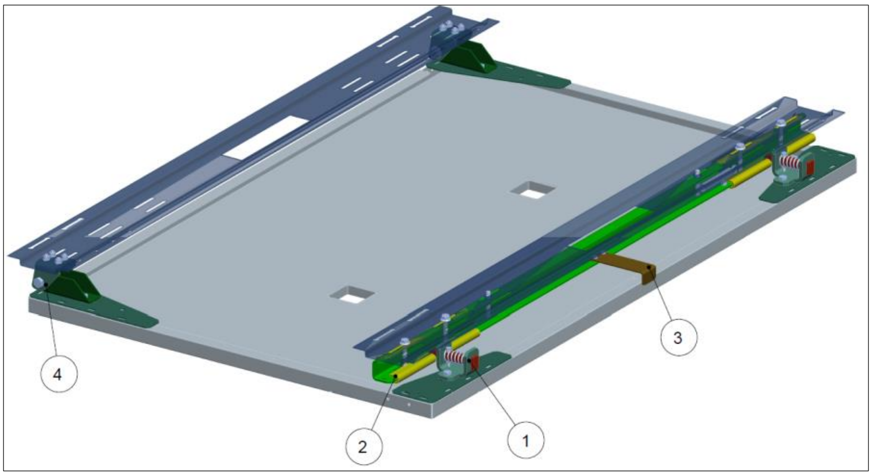


Figure 24 The fixing mechanism concept design

There are 4 main subassemblies and component that form the design. It can be noticed that the controlling plate *3*, which is used to open the ceiling by sliding it to the left, is located in the centre of the ceiling.
Firstly, *balloon number 1*, it is the latch assembly. A spring based latch was designed qualify the demands of simplicity and assemble friendliness.

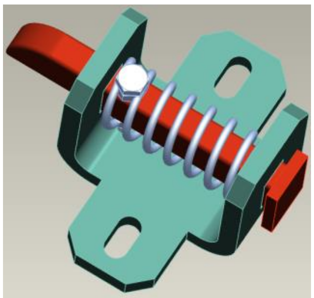


Figure 25 Latch assembly

For the *balloon number 2*, the design of a slidable bar that possesses reasonable stiffness for heavy ceiling is questioned. For simplicity and economical solutions, commercial hollow or solid rectangular bars and tubes were first taken into account. Yet the requirements of machining and sizes raised the demand of customised design of the bar. U profile *5* is believed to offer sufficient stiffness, bolts and nuts in *balloon number 7* provides stiffness against torsion caused by asymmetric load apply on the bar. Combination of the spring *8* and bolt *9* make sure the bar is always under spring load that no unintentional movement is allowed. The support *6* is a bent profile that has the opening or the latch and is shaped so that rotation of the deflection of the bar *5* is minimized.

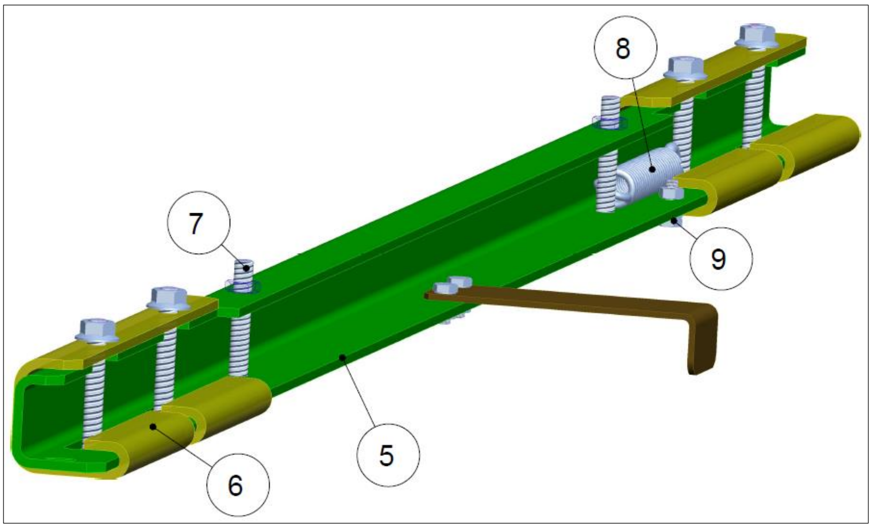


Figure 26 Sliding U profile

The design of the hinge assembly *4* is a modification of KONE's standard solution. A tube is welded to the lower plate to increase stiffness while the upper plate's shape allows ceiling panel edge to movement in confined space.

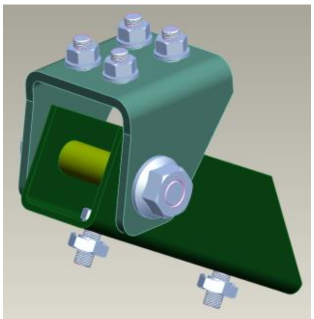


Figure 27 Hinge assembly

3.4.2 Concept study and improvement

Depending on its nature and the working conditions (such as material, load types and temperatures), the procedure of calculation, analysis and study of design or structure will follow a specific theoretical base. The following sections will introduce applicable processes and theory of failure that is believed to be suitable for the ceiling fixing designs.

3.4.2.1. Design study processes

In a rational design procedure, there are 3 principal steps from which the member will be fully studied its performance.

Step 1:

Base one the load types and conditions acting on the member, mode of failure is determined.

Due to the significant role of the material to the mode of failure, primary material selection is also included in this initial step.

Step 2:

Mode of failure now can be quantitatively express, for example, the maximum bending stress derived from the study of the correlations between stress components distribution throughout the cross section of that member.

Step 3:

Depending on the member's material properties, allowable stresses are obtained as a result of experimental observations, analysis or experience with a safety factor taken into account. The safety factor covers uncertainties in service conditions, especially the loads in uniformity of material, or the accuracy of stresses components and relations established in step 2.

$$\sigma_{allowable} = \frac{\sigma_{failure}}{n}$$

Value of n: 1,4 in aircraft and space vehicle applications, whereas 2 to 2.5 where weight of the structure is not a critical constraint.

Step 4: Conclusion of the design of the member can be made by comparing the actual stresses caused the loads and the allowable ones.

3.4.2.2. Theories of failure and static failure

Mechanical failure of a machine part, machine or a structure can be regarded as any behaviour which leads to any change in size, shape or material properties that make it incapable of executing its design functions.

Failure in engineering components can lead to catastrophe in terms of cost and sometimes loss of many lives. Therefore, an engineer's job is to anticipate and plan for possible failure prevention in advance.

The typical sources of mechanical failure in a component or system are:

- Misuse or abuse of that component or system
- Occurrence of errors during assembly operations
- Manufacturing flaws or deficiencies (such as improper heat treatments and casting discontinuities)
- Design errors
- Unexpected working conditions
- Inadequate maintenance

As one of the primary requirements, minimization of the possibility of failure of part or structure is the task for designers. Together with causes of failure, categorizing of failures is also imperative. There are general types of mechanical failure can be included:

- Failure caused by fracture due to static overload, fracture can be brittle or ductile.
- Buckling in column cause by compressive overloading.
- Yield under static loading that result in failure to other components.
- Impact load or thermal shock.
- Fatigue fracture failure.
- Creep failure caused by low strain rate at elevated temperature.
- Combination of stress and corrosion.

- Excessive wear failure.

Within the scope of the thesis work and concept design requirements, materials to be mentioned will be structural steel S235JR. In addition, the study and application of failures will be limited to the ones that are direct functions of the applied loads. Therefore, the following types of failure can be neglected:

- Creep failure
- Buckling and excessive elastic deflection
- And fatigue failure due to dynamic loads

As a result, two basic categories of failure, which is now static failure, remained:

- Plastic strain or distortion failure due to plastic deformation when it reaches a limit value of 0.2% offset of yield point.
- Fracture failure caused by fragmentation into two or more parts of the component.

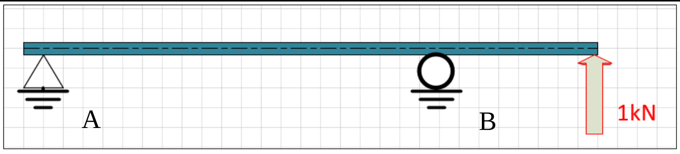
3.4.2.3. Concept study

Applying the preceding works, strength calculation and finite element analysis of the critical components based on static failure theory that allowable shear stress and deflection value obtained by implementing safety factor of 4 and allowable 2‰ of deformation proportional to the component's length.
Material of all components being analysed is structural steel S235JR with the properties: yield strength: 235 MPa, tensile strength: 360 MPa, elastic modulus: 210 GPa.

3.4.2.3.1. Strength calculation of critical components

For faster and more accurate computing, PTC Mathcad 15 was used in strength manual calculation. There are only the latch bar (KM51080632, *figure 28*) and upper hinge plate (KM51080637, *figure 38*) using this method.
The detail structure and achieved results of the calculations are shown in following tables:

Table 7 Calculations of the latch (KM51080632)

Stage	Calculation	Output
Free-body diagram		
Equilibrium equations		

$F := 1000$

Given Equilibrium equation:

$F_A + F_B + F = 0$

$F \cdot 22 - F_A \cdot 45 = 0$

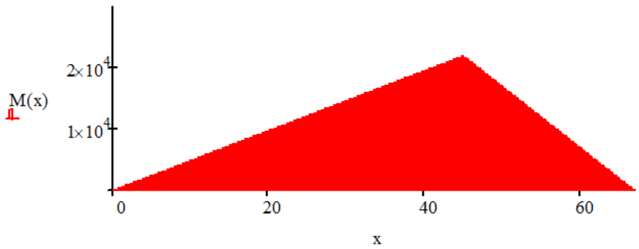
$\text{Find}(F_A, F_B) \rightarrow \begin{pmatrix} \frac{4400}{9} \\ -\frac{13400}{9} \end{pmatrix} \qquad F_A := \frac{4400}{9} \qquad F_B := \frac{-13400}{9}$ — F_A, F_B

Bending moment diagram

Moment function:

$$M(x) := \begin{cases} F_A \cdot (x) & \text{if } 0 < x < 45 \\ \left[F_A \cdot x + (F_B) \cdot (x - 45)\right] & \text{if } 45 \le x \le 67 \end{cases}$$

Bending moment diagram:



$M_{max} := 22000 N \cdot mm$ — M_{max}

$b := 8mm \quad h := 12mm \qquad S_x := \frac{1}{12} \cdot \frac{b \cdot h^3}{\frac{h}{2}} \rightarrow 192 \cdot mm^3$

Maximum bending stress

$$\sigma_{max} := \frac{M_{max}}{S_x} \rightarrow \frac{1375 \cdot N}{12 \cdot mm^2} = 114.583 \times 10^6 \, Pa$$ — σ_{max}

Partial slope equation (0<x<45) obtained by applying integration of moment function :

$$\theta 0i(x) := \int F_A \cdot (x)\, dx \rightarrow \frac{2200 \cdot x^2}{9}$$

Slope equation (0<x<

$$E \cdot I \cdot \theta 0(x, c0) = \theta 0i(x) + c0 \rightarrow E \cdot I \cdot \theta 0(x, c0) = \frac{2200 \cdot x^2}{9} + c0$$

Then slope function (0<x<45) obtained:

$$\theta 0(x, c0, E, I) := \frac{1}{E \cdot I} \cdot \left(\frac{2200 \cdot x^2}{9} + c0\right)$$

When 45<x<67, partial slope function:

$$\theta 1i(x) := \left[\int \left[F_A \cdot x + (F_B) \cdot (x - 45)\right] dx\right] \rightarrow -\frac{(1000 \cdot x - 67000)^2}{2000}$$

$$E \cdot I \cdot \theta 1(x, c1) = \theta 1i(x) + c1 \rightarrow E \cdot I \cdot \theta 1(x, c1) = c1 - \frac{(1000 \cdot x - 67000)^2}{2000}$$

Slope function:

$$\theta 1(x, c1, E, I) := \frac{1}{E \cdot I} \cdot \left[c1 - \frac{(1000 \cdot x - 67000)^2}{2000}\right]$$

We continue with integration to find deflection functions:

0<x<45
:

$$v0i(x,c0) := \int (\theta0i(x) + c0)\,dx \rightarrow \frac{2200\cdot x^3}{27} + c0\cdot x$$

$$E\cdot I\cdot v0(x,c0,C) = v0i(x,c0) + C \rightarrow E\cdot I\cdot v0(x,c0,C) = \frac{2200\cdot x^3}{27} + c0\cdot x + C$$

Deflection function (0<x<45):

$$v0(x,c0,C,E,I) := \frac{1}{E\cdot I}\cdot\left(\frac{2200\cdot x^3}{27} + c0\cdot x + C\right) \rightarrow \frac{\frac{2200\cdot x^3}{27} + c0\cdot x + C}{E\cdot I}$$

45<x<67:

$$v1i(x,c1) := \int (\theta1i(x) + c1)\,dx \rightarrow 33500\cdot x^2 - \frac{500\cdot x^3}{3} + (c1 - 2244500)\cdot x$$

$$E\cdot I\cdot v1(x,c1,C1) = v1i(x,c1) + C1 \rightarrow E\cdot I\cdot v1(x,c1,C1) = 33500\cdot x^2 - \frac{500\cdot x^3}{3} + (c1 - 2244500)\cdot x + C1$$

Deflection function (45<x<67):

$$v1(x,c1,C1,E,I) := \left[\frac{1}{E\cdot I}\cdot\left[33500\cdot x^2 - \frac{500\cdot x^3}{3} + (c1 - 2244500)\cdot x + C1\right]\right]$$

Boundary conditions:

$$E := 210\cdot 10^3 \qquad I := \frac{1}{12}\cdot 8\cdot 12^3 \rightarrow 1152$$

Given

Continuity of the slope at x=45: $\theta1(45,c1,E,I) = \theta0(45,c0,E,I)$

Deflections at beginning, the support and end:

$$v0(0,c0,C,E,I) = 0 \qquad v0(45,c0,C,E,I) = 0$$

$$v1(45,c1,C1,E,I) = 0 \qquad v0(45,c0,C,E,I) = 0$$

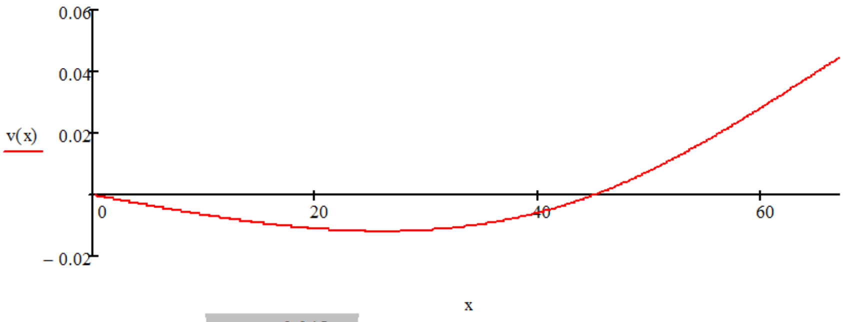
$$\begin{pmatrix} c0 \\ c1 \\ C \\ C1 \end{pmatrix} := Find(c0,c1,C,C1) \rightarrow \begin{pmatrix} -165000 \\ 572000 \\ 0 \\ 22612500 \end{pmatrix}$$

Deflection function for whole latch:

$$v(x) := \begin{cases} v0(x,c0,C,E,I) & \text{if } 0 < x \le 45 \\ v1(x,c1,C1,E,I) & \text{if } 45 < x \le 67 \end{cases}$$

v(x)

Deflection diagram



$v_{max} := 0.045mm$

v_{max}

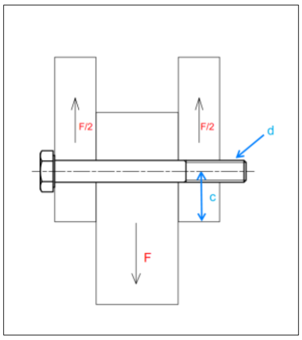
Result table

Type	Allowable value	Maximum value	Status
Stress (MPa)	235	115	OK
Displacement (mm)	0.14	0.045	OK

Comment: Being simplified and idealized radically, the latch bar proved to be strong

	enough. However, it should be noticed that the stress concentration at the hole for the bolt was neglected in this case.	

Table 8 Calculation of the bolt used in hinge assembly (M8x60 St8.8 ISO 4014) and shear stress in hinge plate

Stage	Calculation	Output
	Bolt under double shear load:  Double shear bolt: $c := 12mm$ $F := 2000N$ $d := 8mm$ $t := 3mm$ Shear stress $\tau := \frac{2 \cdot F}{\pi \cdot d^2} = 19.894 \times 10^6 Pa$ Compressive stress (to the hole) $\sigma_H := \frac{F}{d \cdot t} = 83.333 \times 10^6 Pa$ Shear stress to the plate: $\tau := \frac{F}{2 \cdot c \cdot t} = 27.778 \times 10^6 Pa$	
Result table	see result table below	

Type	Allowable value	Maximum value	Status
Shear stress in bolt (MPa)	200	20	OK
Shear stress in plate (MPa)	235	28	OK

According to ISO standard, the bolt used as the follow properties:

Properties class 8.8 (EN ISO 898-1:2013, 8,10)
Tensile strength, R_m, 800 MPa
Stress at 0.2% non-proportional elongation for full-size fasteners, $R_{p0,2}$, 640 MPa
Proof load: M8 21,2kN.

For the permissible design shear stress of the bolt, even though 200 MPa was used, student found it was difficult to find a reliable source to cite and the SFS ISO 989-1 excludes the shear stress.

The M8 bolt and hinge connection design, therefore, concluded to be safe to use.

3.4.2.3.2. Finite element analysis of critical components

For more user friendly and common output unit setup (such as kN or MPa), PTC Pro|Engineer wildfire 5.0 Hamk's license was used.
List of components and assemblies were analysed:

- Latch bar
- Latch and fixing plate assembly
- Upper hinge plate
- Lower hinge plate
- U profile bar

Detail of input and results are shown in tables and figures as follow:

Table 9 Latch analysis

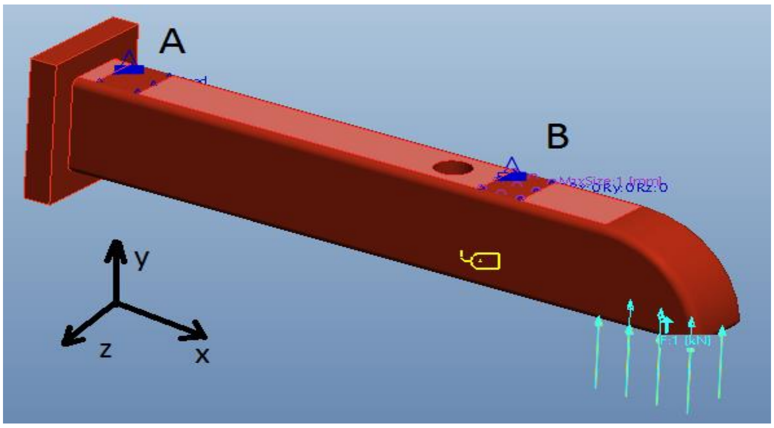
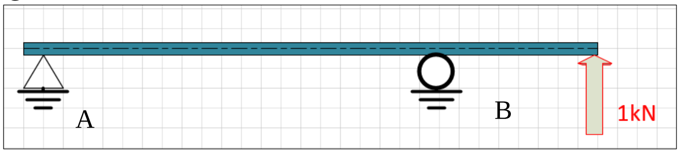
<table>
<tr><td>Type</td><td>Detail: KM51076953 (LATCH)</td></tr>
<tr><td>Input</td><td>


Figure 28 Constraints and load on the latch

Free-body diagram:



<u>Constraints</u>:
<table>
<tr><td rowspan="2">Displacement constraints</td><td colspan="3">Translation</td><td colspan="3">Rotation</td></tr>
<tr><td>X</td><td>Y</td><td>Z</td><td>X</td><td>Y</td><td>Z</td></tr>
<tr><td>Surface A</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td></tr>
<tr><td>Surface B</td><td>Free</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td></tr>
</table>
<u>Load</u>:
Force (surface contact): Direction: Y+ Magnitude: 1kN
</td></tr>
<tr><td>Results</td><td>
<table>
<tr><td>Type</td><td>Allowable value</td><td>Maximum value (von Mises)</td><td>Status</td></tr>
<tr><td>VM Stress (MPa)</td><td>235</td><td>1075</td><td>Examine required</td></tr>
<tr><td>Displacement (mm)</td><td>0.14</td><td>0.03</td><td>OK</td></tr>
</table>
</td></tr>
<tr><td>Interpretation</td><td>As shown in figure 30, refinement of element has been done at location of critical stress. From the maximum von Mise stress ProEngineer calculated, 1075 MPa is too much compare to allowable value at 235 MPa. However, figure 30 indicates that elements at such high stress values concentrated are only in located in very small area compare to the rest of the latch has the stress level at 107 MPa which is total within allowable value.

The stress concentration at such high level in small area can be explained that the rotation around z axis was not allowed at surface B, whereas in real-life situation it is.
In conclusion, the latch design is acceptable.</td></tr>
</table>

	Comparison: The results obtained from Mathcad calculation in *Table 7* are 107 MPa and 0.045mm while the ones from ProEngineer are 107MPa and 0.03. It can be interpreted that the results are reasonably reliable.

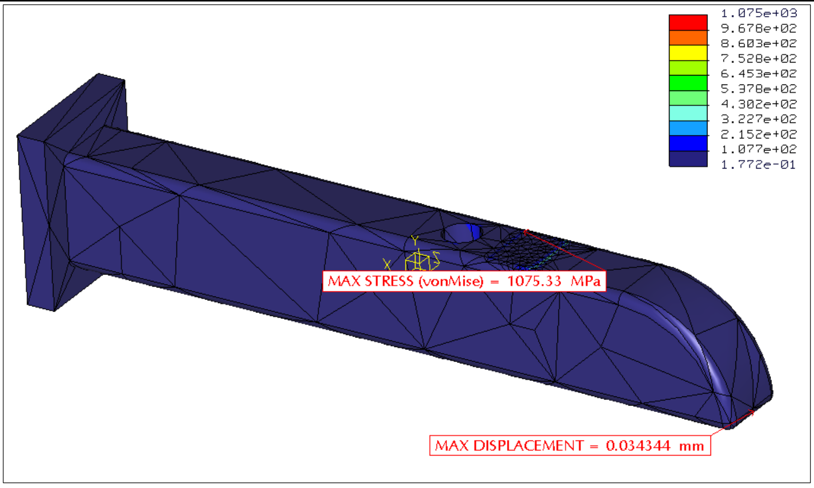


Figure 29 latch analysis

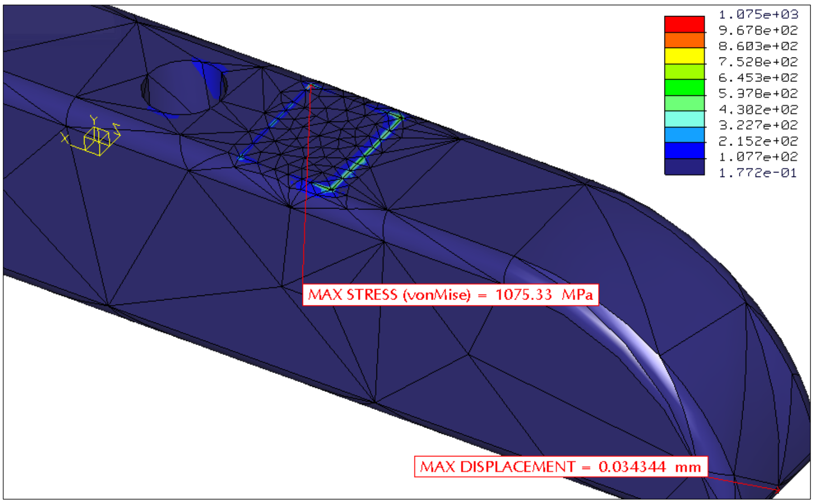
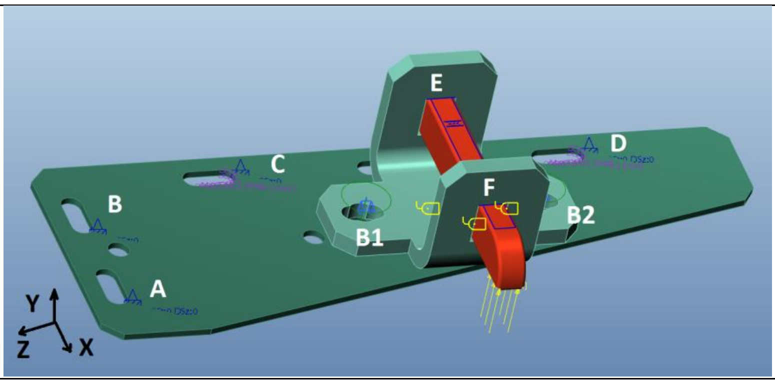


Figure 30 stress concentration in the latch

Analysis of the assembly of the latch and the ceiling fixing plate will be performed in order to study stress distribution in the whole latch connection.

Table 10 Latch and fixing plate assembly

Type	Detail: KM51076954 (LATCH ASM) and KM51080578V00X
Input	

<table>
<tr><td></td><td>
Figure 31 Constraints and load on the latch

<u>Constraints</u>:
<table>
<tr><th>Pin constraint</th><th>Angular</th><th>Axial</th></tr>
<tr><td>A& D</td><td>Fixed</td><td>Fixed</td></tr>
<tr><td>B & C</td><td>Free</td><td>Fixed</td></tr>
</table>
<u>Connections</u>:
- Interfaces: bonded interface of the latch upper surface to the plate surfaces at E & F
- Fasteners: At B1 and B2
Fastener type: bolt. References: edge-edge. Diameter: 8mm steel
<u>Load</u>:
Force (surface contact): Direction: Y+ Magnitude: 1kN
</td></tr>
<tr><td>Results</td><td>
<table>
<tr><th>Type</th><th>Allowable value</th><th>Maximum value (von Mises)</th><th>Status</th></tr>
<tr><td>VM Stress (MPa)</td><td>235</td><td>6225</td><td>Examine required</td></tr>
<tr><td>Displacement (mm)</td><td>-</td><td>5.92</td><td>Examine required</td></tr>
</table>
</td></tr>
<tr><td>Interpretation</td><td>At the thickness of 2 mm, load of 1kN and the assembly is fixed at A,B,C and D seems to be illogical that result extreme high stress and deformation values. However it should be noticed that the overwhelming stresses are only located in small area whereas the area of 623MPa of stress that can cause failure of the design is the one we concentrate, and in this case, scattered within quite significant area (in bright blue).
The design is alarmingly not accepted.</td></tr>
<tr><td>Improvement</td><td>A solution for this is now the assembly will be fixed (to the ceiling) at B1 and B2 (in figure 31). Now, the results are shown in figure 34&35 where the critical area has the stress around 160MPa even though there is 1270 MPa of concentrated stress. Meanwhile, the maximum deflection in this case is 0.25 mm.
Concerning the accuracy of bolt connection set up, surface bonded interfaces at G and H in figure 36 have been applied. The result reveals that even though there are differences in deformation of the plate, shown at C1 and C2 in figure 37, the stress and deflection values are quite similar to each other.
To conclude, the fixing of the assembly needs to be carefully observed. According to the simulation, bolt fixing at B1 and B2 can be considered as a solution.</td></tr>
</table>

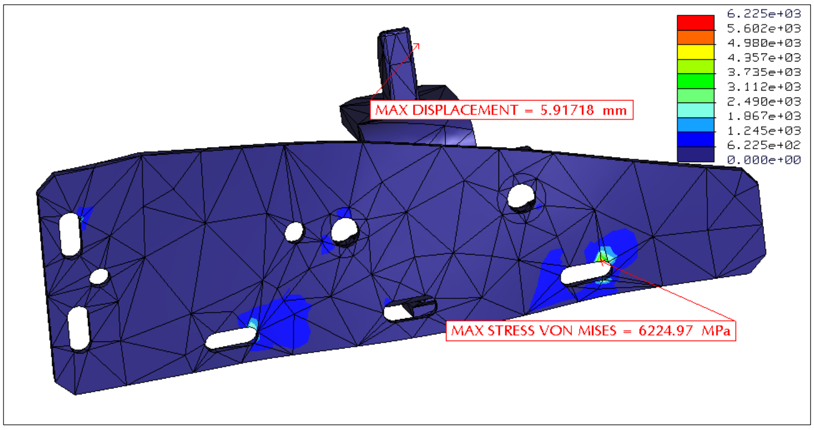


Figure 32 Stress distribution and displacement in original design

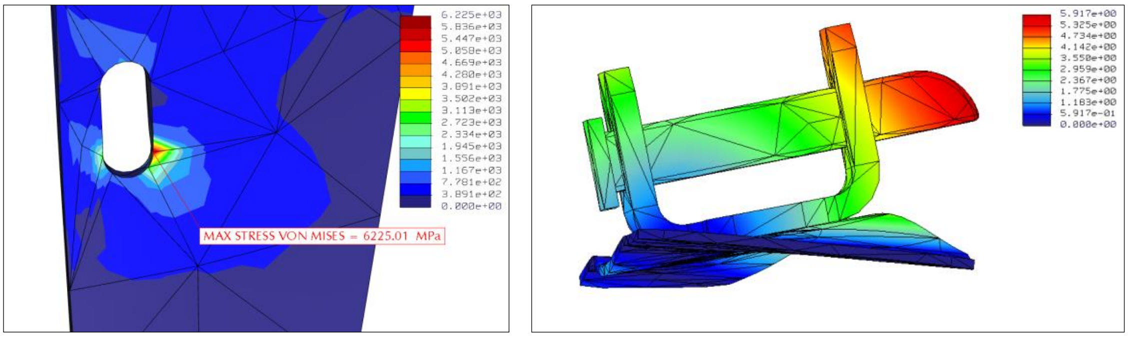


Figure 33   Stress concentration and displaced form.

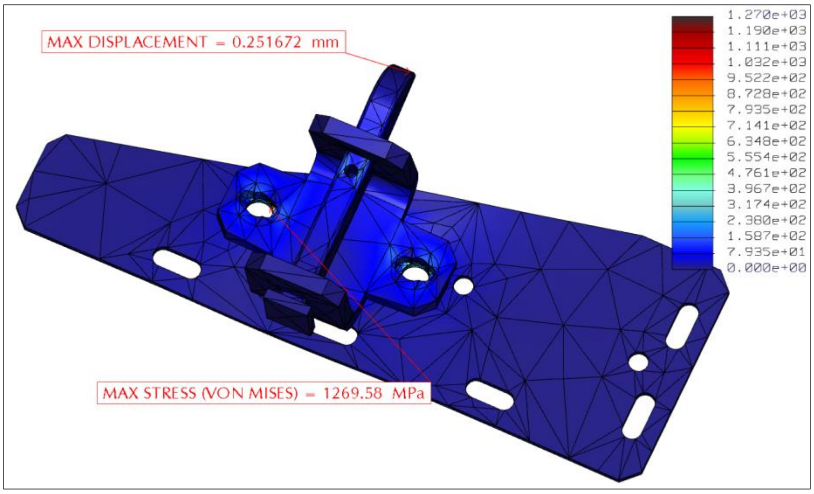


Figure 34   Stress and displacement in suggest solution

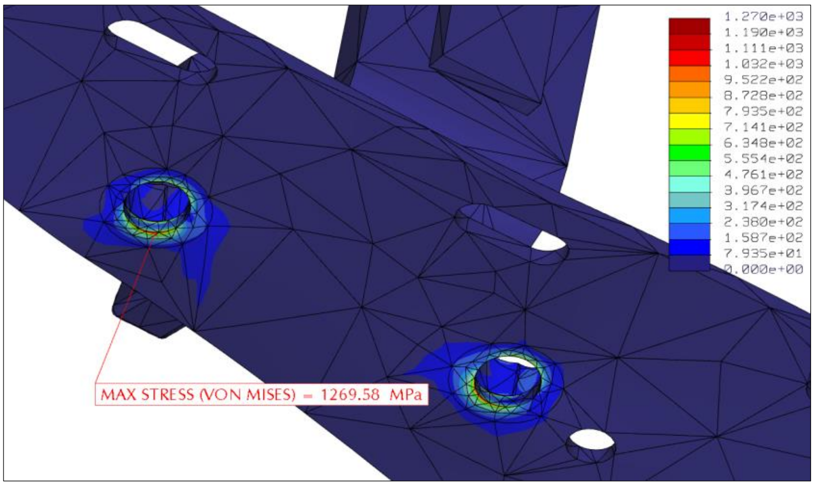


Figure 35   Stress distribution zones

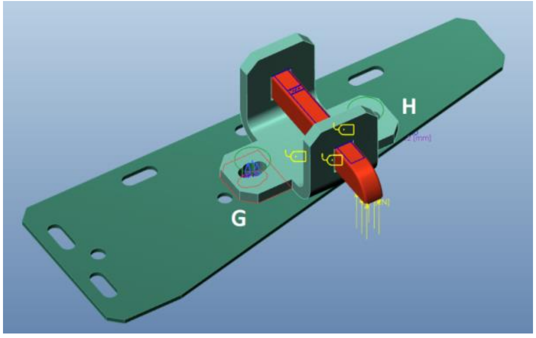


Figure 36 Connection input to Mechanica

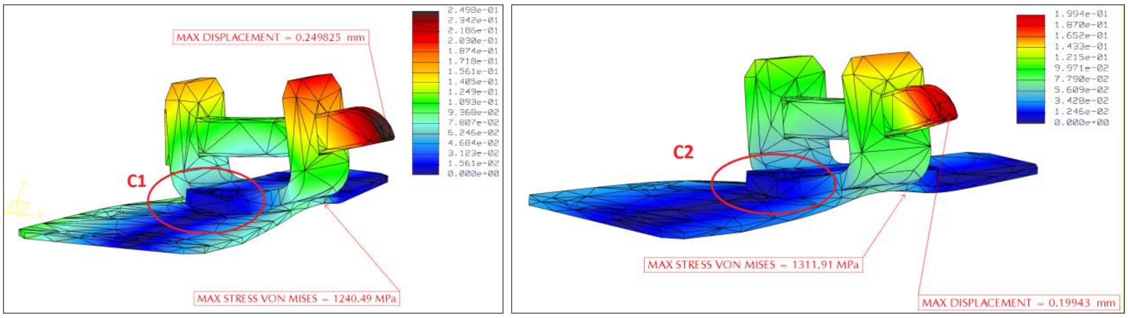


Figure 37 Corresponding deformation.

Operationally, the hinge components are under two load conditions, one is when the ceiling is locked and the load is assumed to share evenly to 4 contact places. For the design of the upper hinge plate, because of the holes' location, analysis in one loading condition would be enough to evaluate its design:

Table 11 Upper hinge plate analysis

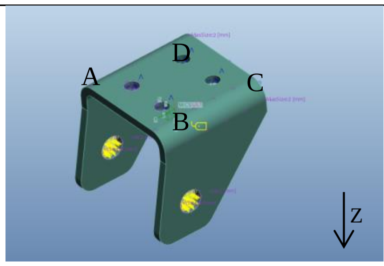
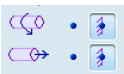
<table>
<tr><td>Type</td><td>Detail: KM51080637</td></tr>
<tr><td>Input</td><td>


Figure 38 Upper hinge plate inputs

<u>Constraints</u>:
<table>
<tr><td>Pin constraint
</td><td>Angular</td><td>Axial</td></tr>
<tr><td>A& B</td><td>Fixed</td><td>Fixed</td></tr>
<tr><td>C & D</td><td>Free</td><td>Fixed</td></tr>
</table>
<u>Load</u>:
Bearing load (surface contact): Direction: *Z+* Magnitude: *1kN/surface*
</td></tr>
<tr><td>Results</td><td>
<table>
<tr><td>Type</td><td>Allowable value</td><td>Maximum value (von Mises)</td><td>Status</td></tr>
<tr><td>VM Stress (MPa)</td><td>235</td><td>1015</td><td>Examine required</td></tr>
<tr><td>Displacement (mm)</td><td>-</td><td>0.18</td><td>OK</td></tr>
</table>
</td></tr>
<tr><td>Interpretation</td><td>As shown in figure 39, even though the highest stress value at 1015 MPa can be neglect-</td></tr>
</table>

	ed due to its very small distribution, the excessive stresses (from 255 MPa) distribute in a noticeable area (approximately 2mm in diameter around the holes). Design improvement is necessary in this case. Comparison:
Improvement	The plate thickness can be increased or changes in the plate width and hole locations

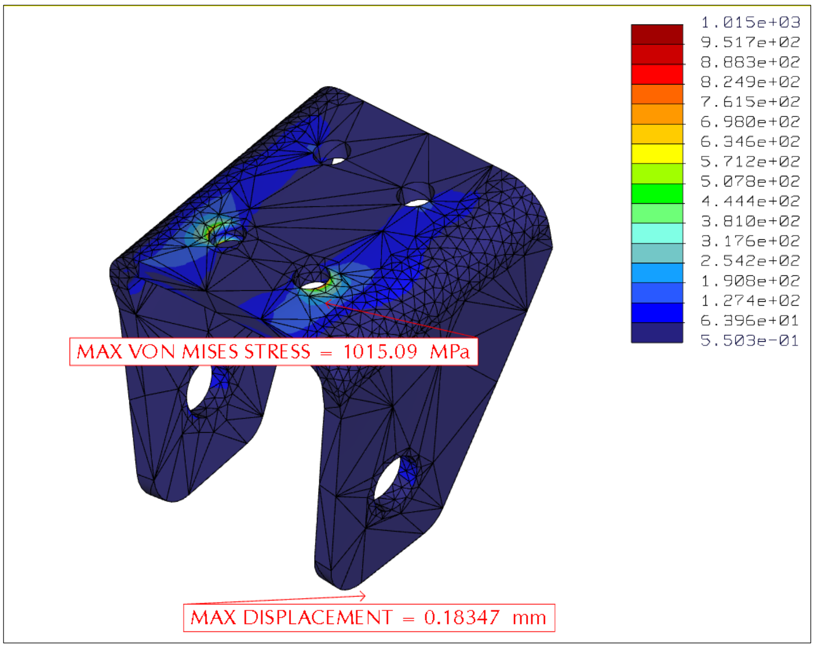


Figure 39 Stress distribution and deformation maginitude

For the lower hinge plate, 2 load conditions will be analysed separately:

Table 12 Lower hinge plate shear stress analysis at opening position

Type	Detail: KM51046679
Input	(see below)

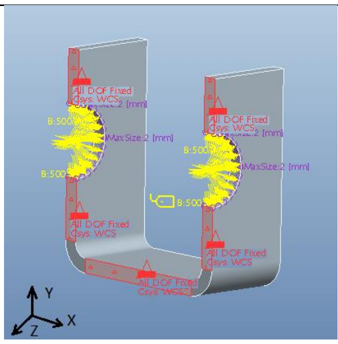


Figure 40 Constraints and load on hinge plate

Constraints:

Displacement constraints	Translation			Rotation		
	X	Y	Z	X	Y	Z
All 3 surfaces	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed

Load:

Bearing load (surface contact): Direction: Z-; Magnitude: 500N/ surface

Results:

Type	Allowable value	Maximum value	Status
VM Stress (MPa)	235	132	OK
Displacement (mm)	-	0.03	-

Interpretation	As shown in *figure 41*, shear stress concentration and magnitude are within the allowable boundary. Conclusion: hinge plate design at opening position is *acceptable*

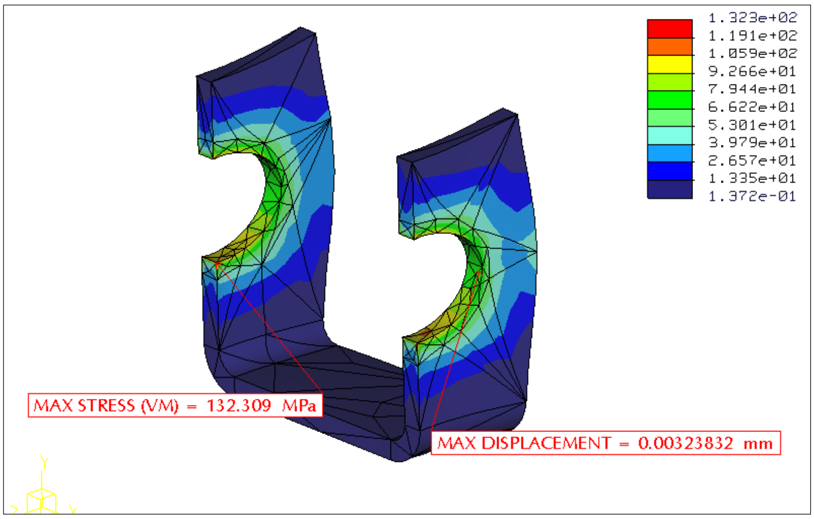


Figure 41 Hinge plate shear stress at opening position

Table 13 Lower hinge plate shear stress analysis at closing position

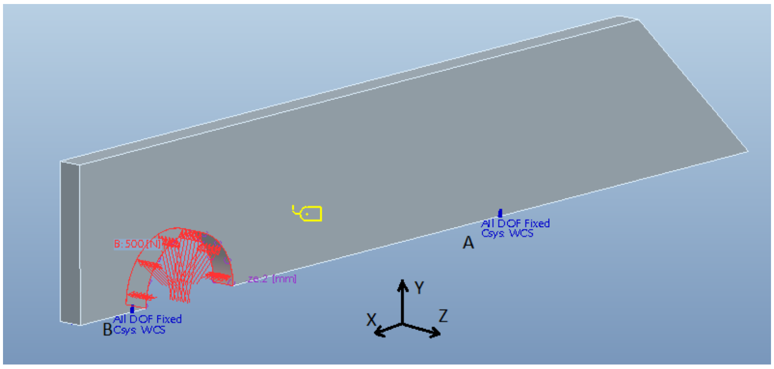
<table>
<tr><td>Type</td><td>Detail: KM51046679</td></tr>
<tr><td>Input</td><td>


Figure 42 Constraints and load on hinge plate

<u>Constraints</u>:
<table>
<tr><td rowspan="2">Displacement constraints</td><td colspan="3">Translation</td><td colspan="3">Rotation</td></tr>
<tr><td>X</td><td>Y</td><td>Z</td><td>X</td><td>Y</td><td>Z</td></tr>
<tr><td>Surface A& B</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Fixed</td></tr>
</table>
<u>Load</u>:
Bearing load (surface contact): Direction: Y+; Magnitude: 500N
</td></tr>
<tr><td>Results</td><td>
<table>
<tr><td>Type</td><td>Allowable value</td><td>Maximum value</td><td>Status</td></tr>
<tr><td>VM Stress (MPa)</td><td>235</td><td>60</td><td>OK</td></tr>
<tr><td>Displacement (mm)</td><td>-</td><td>0.02</td><td>-</td></tr>
</table>
</td></tr>
<tr><td>Interpretation</td><td>The hinge plate design in this case is acceptable.</td></tr>
</table>

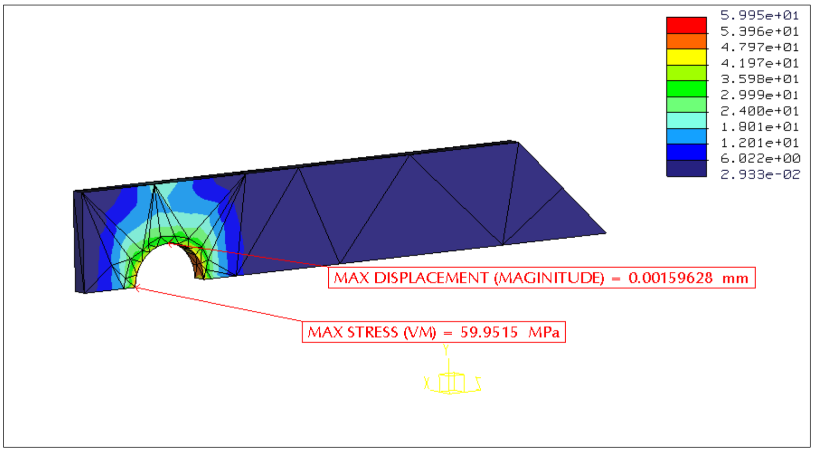


Figure 43 Hinge plate maximum stress and displacement

Table 14 Hinge assembly analysis at opening position

Type	Detail: KM51080587
Input	(see figure, constraints and load below)

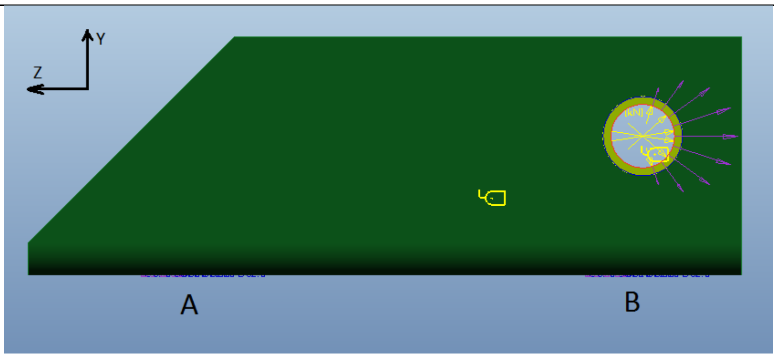
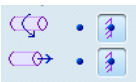


Figure 44 Constraints and load on hinge plate

Constraints:

Pin constraint 	Angular	Axial
B	Fixed	Fixed
A	Free	Fixed

Load:
Bearing load (surface contact): Direction: Z-; Magnitude: 1kN

Result:

Type	Allowable value	Maximum value	Status
VM Stress (MPa)	235	617	OK
Displacement (mm)	-	0.07	-

Interpretation: According to *figure 45*, area that has noticeable stress value should be 186 MPa which is allowable. The excessive levels that peaked at 617 MPa is neglectful, similar distribution can be found in *figure 48*
The design is OK

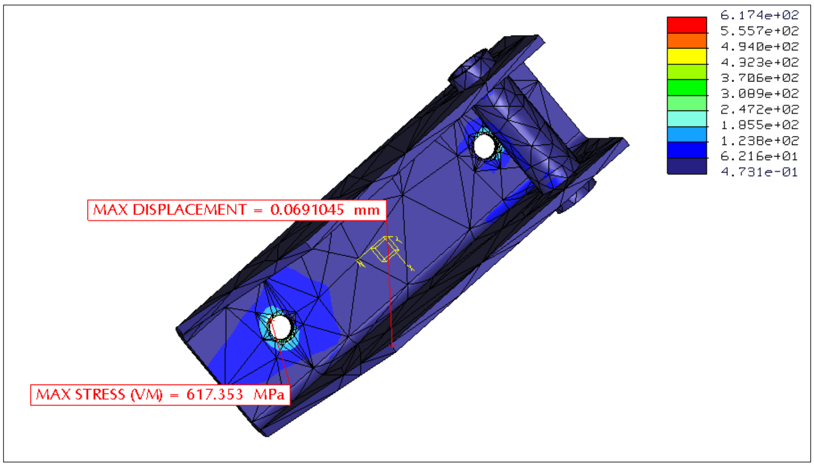


Figure 45 Hinge assembly maximum von Mises stress at open

Table 15 Hinge assembly analysis at closing position

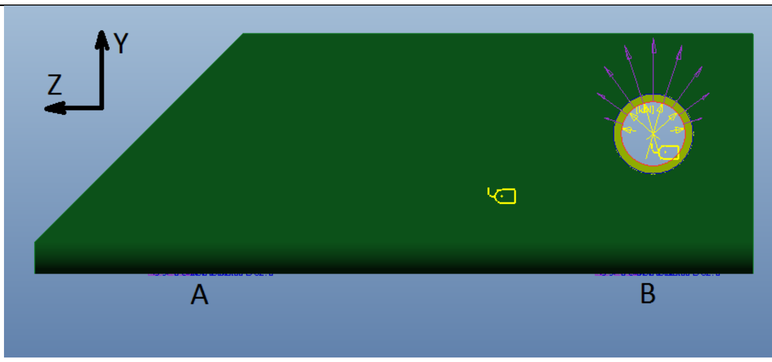
<table>
<tr><td>Type</td><td>Detail: KM51080587</td></tr>
<tr><td>Input</td><td>

Figure 46 Constraints and load on hinge plate

Constraints:
<table>
<tr><td>Pin constraint</td><td>Angular</td><td>Axial</td></tr>
<tr><td>A& B</td><td>Fixed</td><td>Fixed</td></tr>
</table>
Load:
Bearing load (surface contact): Direction: Y+ Magnitude: 1kN</td></tr>
<tr><td>Results</td><td>
<table>
<tr><td>Type</td><td>Allowable value</td><td>Maximum value</td><td>Status</td></tr>
<tr><td>VM stress (MPa)</td><td>235</td><td>811</td><td>Examine required</td></tr>
<tr><td>Displacement (mm)</td><td>-</td><td>0.05</td><td>OK</td></tr>
</table></td></tr>
<tr><td>Interpretation</td><td>Figure 48 indicates that stresses distribute in the same manner as interpreted in Table 14. However, the stress value is 243 MPa in this case, this fact dictates that the design needs to be improved</td></tr>
<tr><td>Improvement</td><td>Taken into consideration the interpretation has been done from Table 14 and 15, the plate should be thickened to 3mm.</td></tr>
</table>

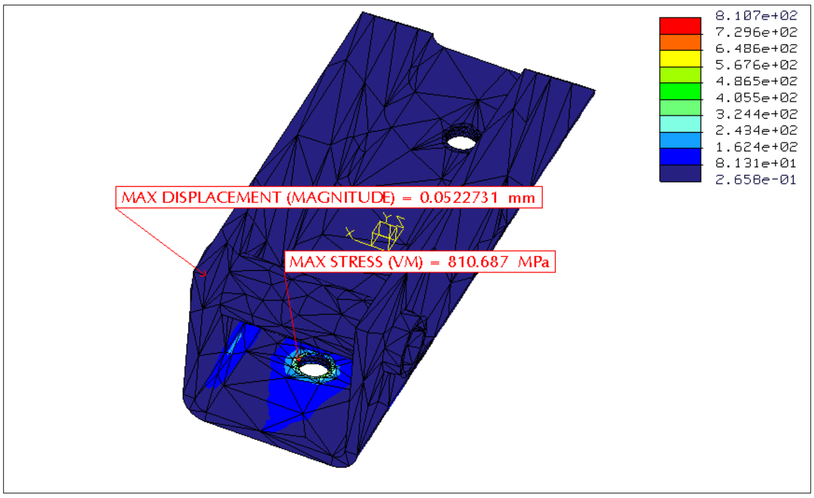


Figure 47 Maximum von Mises stress and deformation at closing

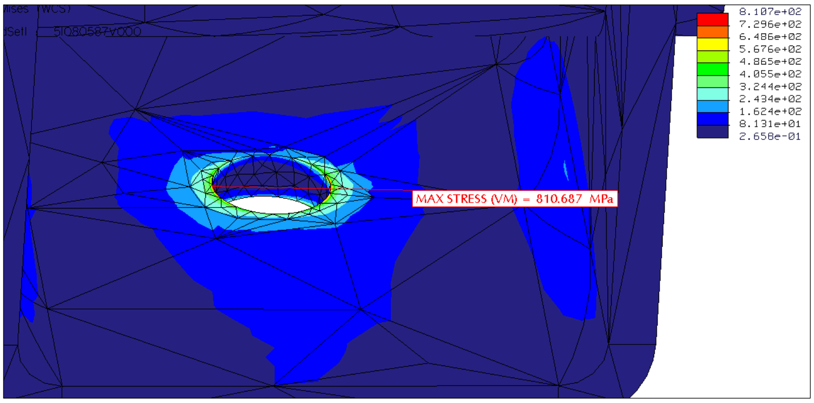


Figure 48 Stress concentration and distribution

On the car roof, the U profile plate is considered as a critical component that needs to be analyzed. There will be two loading condition of the profile, one is at ceiling fixed situation, the other is closing state of the ceiling when temporary load applied and the latch will retract accordingly to fix the ceiling.

Table 16 U profile analysis at closing position

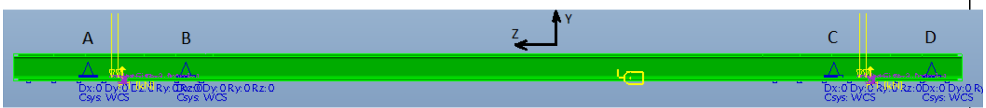
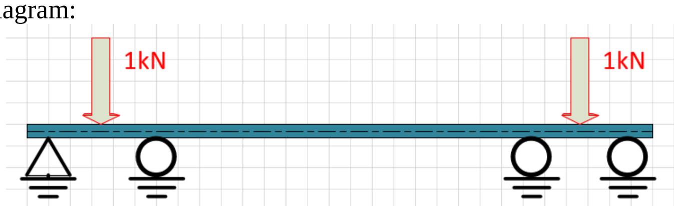
<table>
<tr><th>Type</th><th>Detail: KM51076805</th></tr>
<tr><td>Input</td><td>


Figure 49 Constraints and load on the latch

Free-body diagram:



Constraints:

<table>
<tr><td rowspan="2">Displace-ment</td><td colspan="3">Translation</td><td colspan="3">Rotation</td></tr>
<tr><td>X</td><td>Y</td><td>Z</td><td>X</td><td>Y</td><td>Z</td></tr>
</table>
</td></tr>
</table>

constraints						
A	Fixed	Fixed	Fixed	Free	Fixed	Fixed
B,C & D	Fixed	Fixed	Free	Free	Fixed	Fixed

Load:

Force (surface contact): Direction: *Y*-; Magnitude: *1kN/ surface*

Idealization:

- Shear pair: midsurfaces for the whole profile were created by using *insert>midsurface>shell pair.*

Results

Type	Allowable value	Maximum value (von Mises)	Status
VM Stress (MPa)	235	638	Examine required
Displacement (mm)	2.12	0.05	OK

Interpretation	As shown in *figure 52*, refinement of element has been done where critical stress located. From the maximum von Mise stress ProEngineer calculated, 638 MPa is too much compare to allowable value at 235 MPa. However, *figure 52* also indicates that elements at such high stress values concentrated are only in located in very small area compare to the rest of the latch has the stress level at 107 MPa which is total within allowable value. The design is OK
Improvement	However, in order to minimize stress concentration, rounded corner is advisable.

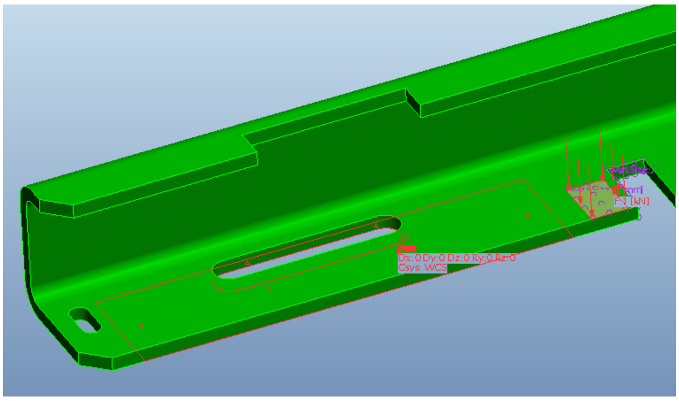


Figure 50 Force applied on profile surface

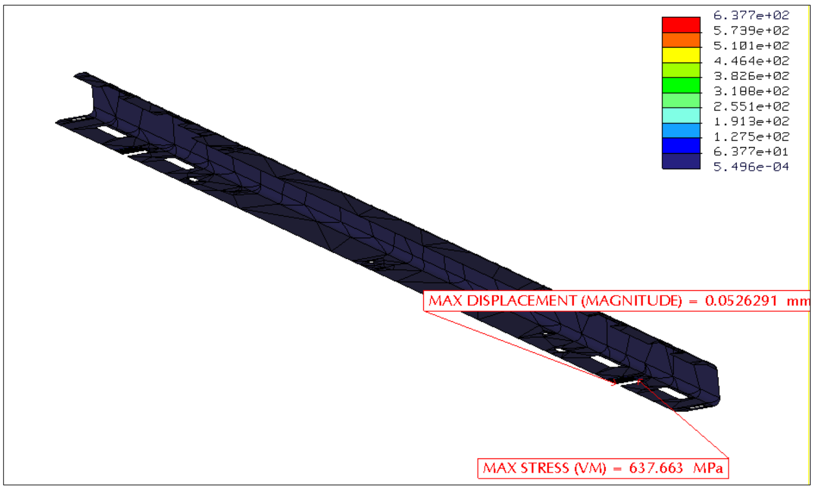


Figure 51 Analysis values

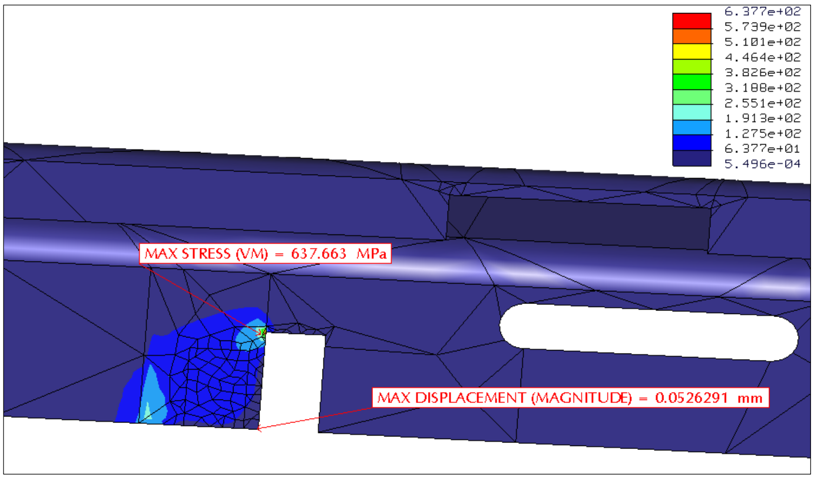
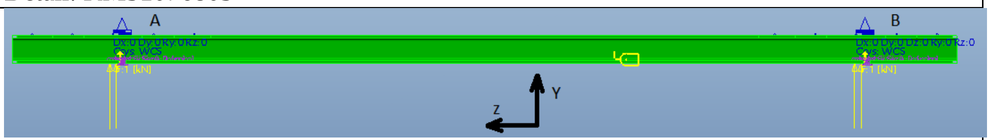
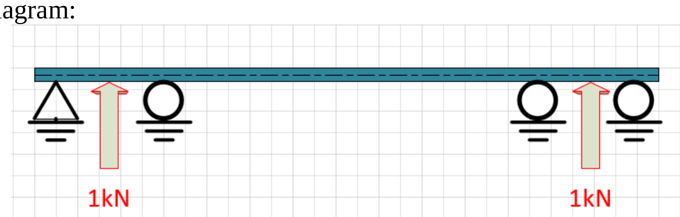


Figure 52 Stress distribution

Table 17 U profile analysis during ceiling closing

<table>
<tr><td>Type</td><td>Detail: KM51076805</td></tr>
<tr><td>Input</td><td>


Constraints and load on the latch
Free-body diagram:


Constraints:
<table>
<tr><td rowspan="2">Displacement constraints</td><td colspan="3">Translation</td><td colspan="3">Rotation</td></tr>
<tr><td>X</td><td>Y</td><td>Z</td><td>X</td><td>Y</td><td>Z</td></tr>
<tr><td>A</td><td>Fixed</td><td>Fixed</td><td>Fixed</td><td>Free</td><td>Fixed</td><td>Fixed</td></tr>
<tr><td>B,C & D</td><td>Fixed</td><td>Fixed</td><td>Free</td><td>Free</td><td>Fixed</td><td>Fixed</td></tr>
</table>
Load:
Force (surface contact): Direction: Y+ Magnitude: 1kN
</td></tr>
<tr><td>Results</td><td>
<table>
<tr><td>Type</td><td>Allowable value</td><td>Maximum value</td><td>Status</td></tr>
<tr><td>VM Stress (MPa)</td><td>235</td><td>1472</td><td>To be check</td></tr>
<tr><td>Displacement (mm)</td><td>2.12</td><td>0.55</td><td>OK</td></tr>
</table>
</td></tr>
<tr><td>Interpreta-tion</td><td>From figure 54, stress values in noticeable areas is 191 MPa.
The design is OK</td></tr>
</table>

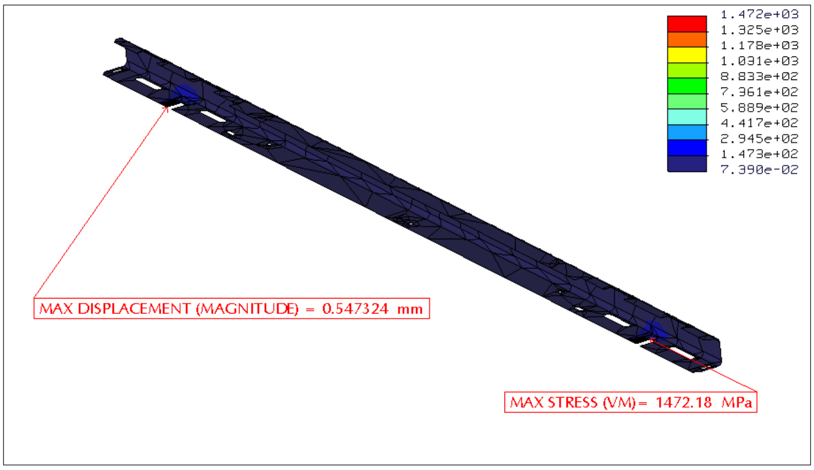


Figure 53 Analysis values in closing

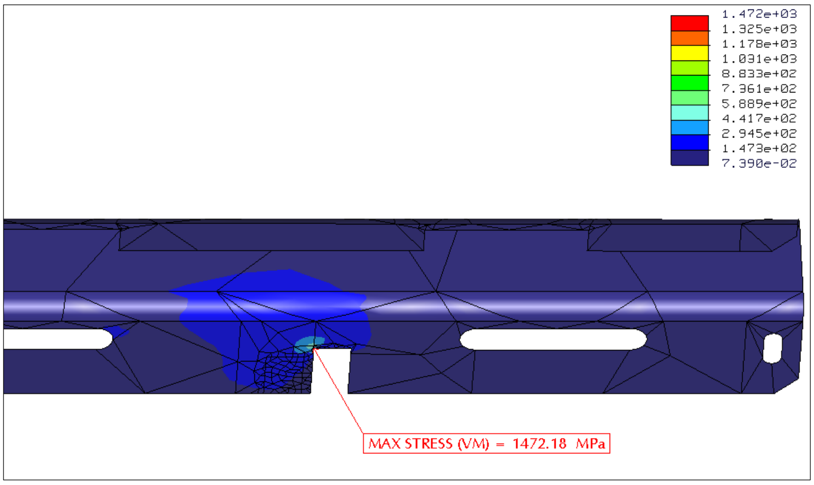


Figure 54 Maximum stress in closing

3.4.2.4. Modifications and improvement requirements

Requirement of modifications and their status obtained from the analysis results will be listed in *Table 18*

Table 18 Design modification

Improvement/ modification	Detail	Status
Fixing location of the latch assembly	Table 10 Component: KM 51080578V00X	Standby: further discussion required
Thickness of the plate	Table 11 Component: KM51080637	Standby
Thickness of the plate	Table 15: Component: KM51080587	Standby
Round corners	Table 16 Component: KM51076805	Done

3.5 The concept design conclusion

Despite the fact that many ideas were introduced, the expected outcome of the work for a functioning fixing mechanism is still questionable.
Concept design competence and engineering design skills, which includes finite element analysis and strength calculation, need to be improved.

Student encounters difficulties to draw a concrete conclusion based of results acquired from Pro|Engineer Mechanica or finite element analysis programs in general. In fact, the level of confidence will increase remarkably when there are separate calculation results to compare to. That leads to a personal principle that can be applicable in future work is that either the analysis skills are proficient enough or strength of material background should be knowledgeable so that the design work can be implemented professionally, safely and accurately. And last but not least, experience and quick-learning skills are always indispensable.

As a whole, being aware of the fact that concept design processes and work flow differentiate case by case, student still have had gain reasonable experience in conceptual design thanks to the approachable at challenging level, yet practical and strict in requirements kind of work.

4 CONCLUSION

The thesis work presented an invaluable opportunity for developing fundamental skills and experiences in product design and development, especially conceptual design ones. Furthermore, working with senior engineers at KONE did help the student not only obtain a better understanding but also necessary skills to work in elevator car engineering and design.

Even though flaws and mistakes are inevitable and the final judgment of the dissertation’s results shall be made after the submission of the report, the thesis work was completed in time and can be considered as the best work that the student can offer within the period of approximately three months. Student also strongly hopes that the work, design or theoretical portion could be useful in some extent, either for KONE or HAMK practically and academically.

From the work, student experiences the limitations of his knowledge and competence in mechanical engineering or elevator technology. Some of which can be understandable due to his limited time in the industry, but the others raises a demand of further study, training and practice that becomes a must when he choose mechanical engineering design as a career path.

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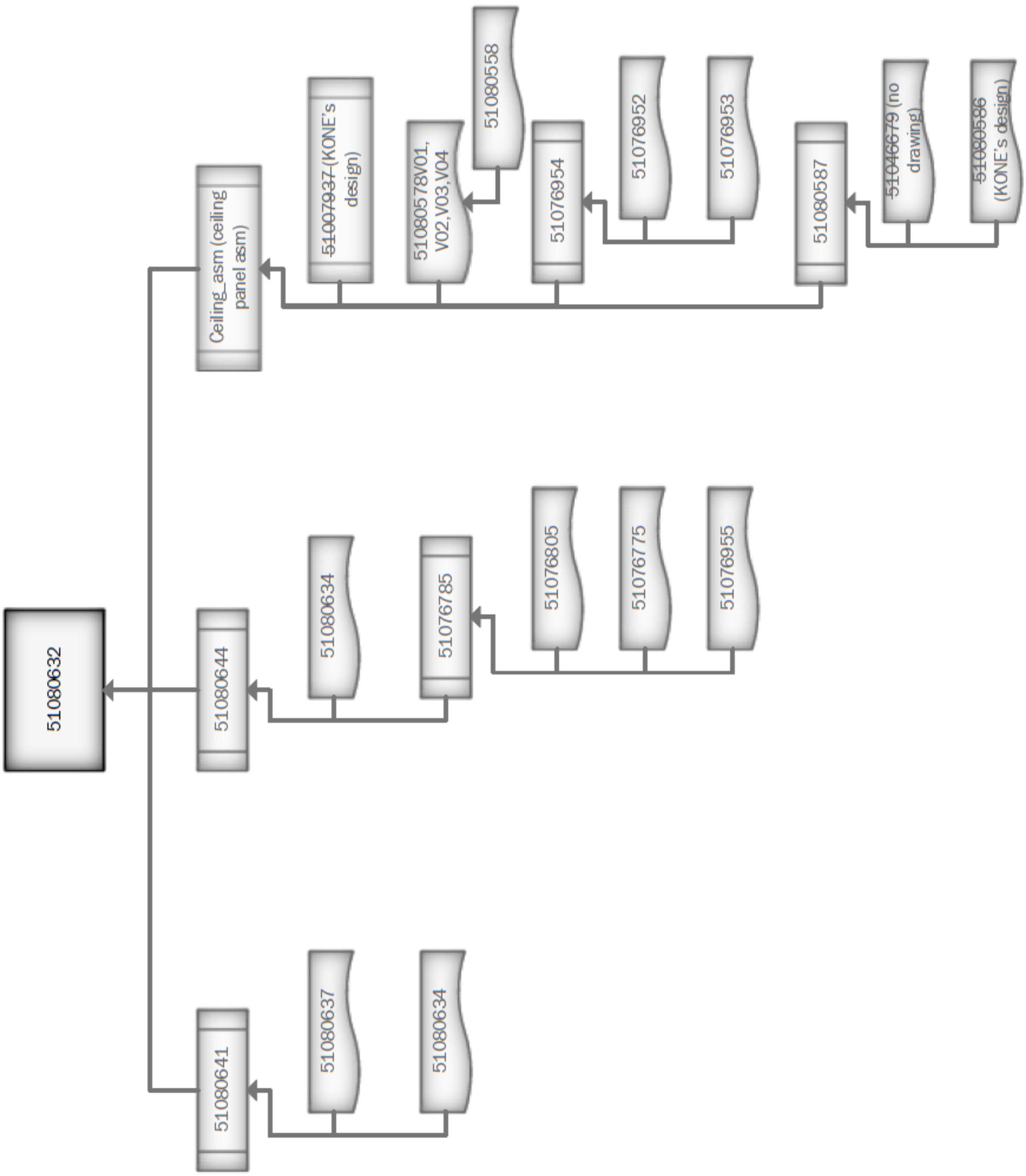
Appendix 1

MANUFACTURING DRAWINGS

MAP OF DRAWINGS



[19 manufacturing drawings excluded from public version]