Process report

AD8-ID3 2008
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Title page

8th Semester

Industrial Design

Institute of Architecture & Design

Aalborg University

Title

E17

Theme

Advanced Integrated Design

Group

3

Project period

February 4th 2008 – May 2nd 2008

Supervisors

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Pages

116

Synopsis

This 8th semester project concerns the main theme Advanced Integrated Design. The project is made in collaboration with the developer and manufacturing company of earthmoving equipment, A/S Hydrema in Støvring, Denmark.

The basis of the project is use-, user investigations and an ongoing information exchange with A/S Hydrema. The result of the project is an excavator with increased lifting power through an extendable counterweight and improved stability and off road capability by implementing four tracks instead of wheels. The resulting excavator is evaluated according to cost vs. benefits, ease of implementation etc.

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Preface

The design group would like to thank A/S Hydrema (Hydrema) for the collaboration, Michael at Spørring Grusgrav, and I.F. Nedbrydning, with special regards to Morten Viborg, for the enthusiastic participation in the initial research and the concept generation.

Instructions for reading

The project is documented in two reports; A process report and a product report. The process report contains five chapters matching the five phases of the process.

Phase 0

Project planning

Phase 1

Research and analysis

Phase 2

Concept generation

Phase 3

Concept development and detailing

Phase 4

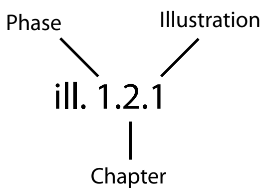
Final detailing and reflection

During the process each phase has been documented in terms of text and illustrations but the main documentation of the process has been made after the concept has been developed.

The product report describes the excavator regarding the design and details, target group as well as market and business strategy for realizing the excavator.

It is recommended that the reader reads the product report first to get an overview of the final product.

Harvard style is used for referring to all sources. The lists of references and illustrations are located in the back of the report. When referring to appendix and illustrations the following format will be used:



ill. 0.1.1

The process report is supplemented by a CD containing further documentation on the project:

I. Appendix

1. Study guide
2. Situated interviews
    a. Forchhammersvej
    b. Algade
    c. Nordkraft
3. Presentations at Hydrema
    a. 10/3: Concept presentation
    b. 31/3: Meeting at Hydrema
    c. 14/4: Product Presentation
4. First visit at Hydrema
5. Sketching catalogue
6. Finite element analysis on hinges, Mathcad and Excel sheets
7. Cost price, Excel sheet
8. Material handed out by Hydrema
9. Application sheet for M1700C

II. Technical drawings of counterweight

III. Process report

IV. Product report

V. Pictures from the process

Contents


HITACHI

Approach

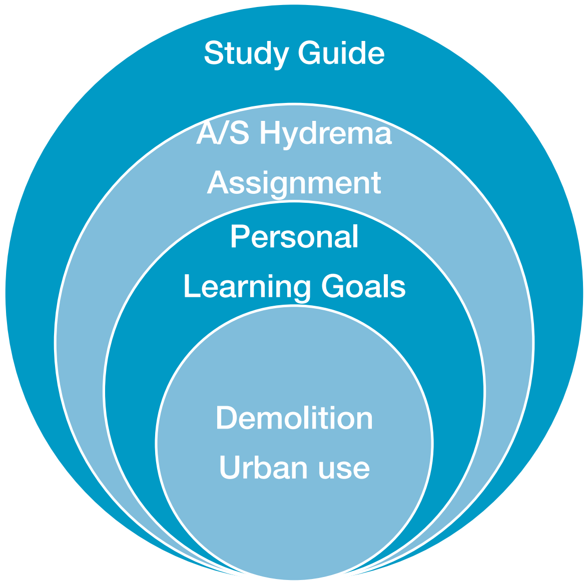
The initial frames for the project are given by the study guide and Hydrema. The following describes how the frames are handled and adjusted to the personal interests of the design group.

Introduction

The 8th semester project concerns the design of an excavator in cooperation with Hydrema.

The context for the project's preliminary focus, demolition and urban areas, is chosen out of interests in the group for development of a design concept.

The cooperation is based on contact with Tytte Hagen Johnsen, in-house designer and Thorkil Iversen, head of research and development, throughout the process and at status presentations at Hydrema. Hereby the design team experiences design in practice by using expert knowledge from a company as well as receiving feedback in a nearer-authentic way than in previous projects. The challenge of the project has been to satisfy Hydrema by applying theoretical design methods to a project, and following the restrictions from the study guide [Appendix 1] as well as satisfying personal interests.



ill. 0.1.2

Advanced Integrated Design

The term advanced integrated design is the main theme of the project. The theme is interpreted in terms of the understanding of the design group:

Design, where considerations regarding technology, function, use, form, production and manufacturing costs gather a complete design solution, integrated on a high level with a broad perspective of considered aspects, that within a certain timeframe is realistic for a company to produce and sell.

Hydrema Assignment

Hydrema is seeking a new norm-breaking conceptual solution for an excavator. The assignment stated by Hydrema is very wide and only defined by potential focus areas; technique, interaction and mobility and wishes for the excavator concept. The approach of the design group to the assignment is based on personal interests. The areas to focus at are in the initial phase stated to be mobility and technical solutions. The assignment is throughout the process made specific in terms of a problem statement and the focus area of the concept.

Learning objectives

Within the frames stated by the Study guide the design group interprets and specifies the learning objectives to satisfy personal goals for the semester.

The specification of the learning objectives is an ongoing process throughout the project. Further solutions and decisions in the process are made based on the stated objectives.[Appendix1]

- To display an understanding of physical form and physical function of the excavator. Furthermore to display an understanding of the relationship between physical form and physical function, overall as well as selected details of the excavator. This also includes to display an understanding of the process the product is included in seen from a selected user(s) point of view. E.g. the operator, the assembly line, the contractor etc.
- Display knowledge of project management through use of appropriate methods and tools for controlling the development process within a given time frame. Hereby controlling the process towards production oriented and market oriented product development in practice.
- Display knowledge of company culture and market culture. The company culture is defined as being the development culture of Hydrema products, core competences and main values of Hydrema, product restrictions and service policy.
- Display knowledge of technology scanning hereby displaying an understanding of the technology of the excavator and new/existing technologies from related products. This also includes scanning of competitor products and market trends regarding style, use, technology and function of the excavator.
- Display knowledge of incorporeal rights including patent protection.
- Select central elements within the solution which is of special importance for the concept and specify it according to relevant issues as technical details, kinematics, materials, surfaces, jointing etc.
- Estimate the production cost of central components as well as the whole according to given amount. (Including installation if relevant).
- Apply digital design principles as well as analogue design principles and be able to relate both principles. Furthermore display knowledge of application in long distance collaborations between cross disciplinary teams which means choice of software, file formats, settings etc.
- Display knowledge of the generation of product variances through reverse engineering interplay between physical and digital model. The elements of the existing Hydrema excavators are used for reverse engineering regarding internal elements of the excavator, the boom, production and manufacturing methods and joints.
- Carry out a Finite Element simulation of a selected component(s) and suggest variance and/or component improvements based on a qualitative assessment of the results.

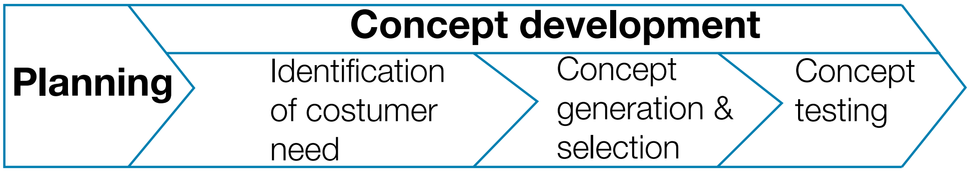
Project management

The project has been divided into phases which are described in the following phaseplan.

The structure of the planning is based on the generic product development process of Eppinger & Ulrich (Eppinger & Ulrich p.14). The phases of the model are interpreted to fit the learning objectives of the semester and the time frame for the project.

The content of the phases are adjusted throughout the process as the focus of the project is specified.

ill. 0.3.1



5/2: First visit Hydrema

Phase 0: Planning

(4/2 - 7/2)

Objectives/activities:

Articulate project frame

Articulate assignment

Project planning (phases)

Project overview/definition

Methods & tools:

Generic product development process

Study guide

Learning objectives

Timetables

Milestones

Microsoft Office OneNote

Output:

Initial assignment

Areas of interests

Phase 1: Research and analysis

(8/2 - 16/2)

Objectives/activities:

Company profile

Excavators - use, function, users

Benchmark: market/competitors

Locate external contacts

Usecases

Methods & tools:

Mindmapping

SWOT analysis

User investigation

Product analysis

Situated interviews

Michael (gravel digging site)

Morten (I.F. demolition)

Inspiration and reasearch of other industries

Use cases (storytelling)

Output:

Design brief

Problem statement

Further questions for Hydrema

Phase 2: Concept generation

(17/2 - 10/3)

Objectives/activities:

Create and select functional principles

Formulate principles into concepts

Styling of the concepts

Evaluation of concept regarding users

Concept presentation

Methods & tools:

5-min sketch

Sketch on mechanisms

Moodboards/Shapeboards

Adobe Photoshop

Context/actor diagram

Situated interview

Output:

Three concepts with functional principles and styling.

ill. 0.3.2

System level Design

Detail design

Production Ramp-up

10/3: Second visit Hydrema - Concept presentation

Phase 3: Concept development and detailing
(11/3 - 14/4)

Objectives/activities:

Evaluation of concepts based on company presentation

Choice of concept for further development

Research

Alternative product architecture

Methods & tools:

Use cases (documentation)

Tjalve

Onck's

SolidWorks

Adobe Illustrator

Output:

Graphical representation of the concept.

SolidWorks model of concept

Final concept for production and manufacturing

31/3: Meeting Hydrema

1/4-4/4: Woofie workshop

14/4: Third visit Hydrema - Product presentaion

Phase 4: Final detailing and reflection
(12/4 - 30/4)

Objectives/activities:

Doing final detailing on the product (calculation, simulation, drawings etc.)

Documentation of the process

Documentation of the product

Process reflection

Methods & tools:

Adobe Illustrator

Adobe Indesign

Adobe Photoshop

SolidWorks

Output:

Detail descriptions

Process report

Product report

30/4: Project hand-in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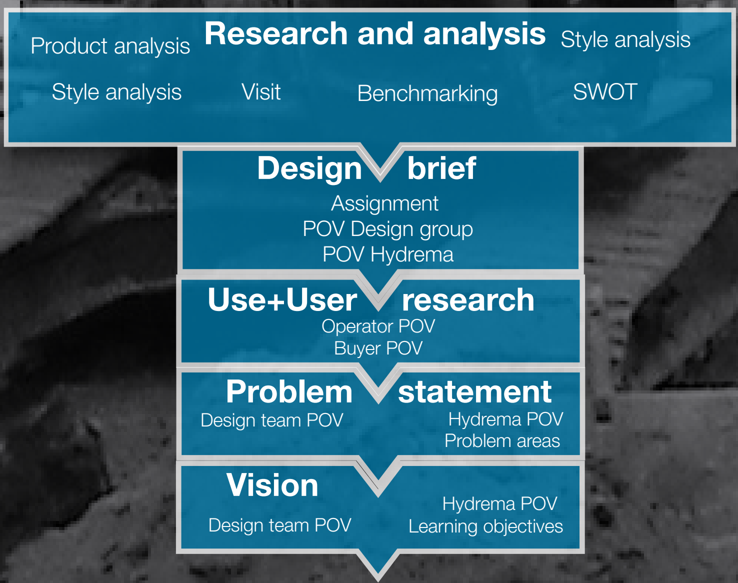
Phase 1: Designbrief



In this phase, the design group forms a basic understanding of Hydrema, their products, visions and markets. Further use and user investigations frame the problem areas regarding the context and the function of the excavator. The first part of phase 1 deals with defining the design brief based on the study guide, the assignment from Hydrema and initial research and analysis. Second part concerns use and user research. Based on the initial research and learning objectives, the initial problem areas for the project are defined.

Design brief

The following chapter is the documentation of the initial research of phase 1. The results are used to form the design brief.

Purpose

The design brief is used to create an understanding between the client and the designer – in this case between the design group and Hydrema. The brief serves as an essential point of reference for both parties. The design brief ensures that important issues are considered and questioned before the designer starts to work. The design brief can be written of either the client or the designer. [Clear Design UK]

In this project the design brief is formed by the design group and is used to create a common base for the design group and an initial direction of the project.

The design brief consists of a company profile description, SWOT, benchmarking and product, style and context analysis where the values of Hydrema are considered together with the company mission statement and vision.

1st visit at Hydrema

As an introduction to the semester and the project, the design groups visits Hydrema at the company headquarter in Støvring. At the first meeting with Hydrema, the design groups are introduced to the company contacts; Thorkil Iversen, head of research and development, and Tytte Hagen Johnsen, in-house industrial designer.

The company profile, product history, and details of the excavators M1400C, M1620C and M1700C, series 2, are presented together with the assignment and areas of focus (Appendix 8).

The excavator M1400 and the 10T dumper are made available for each design group to experience their functions and the man-machine relationship of the Hydrema earth moving equipment.

Outcome

This visit provides the design group with a basic understanding of the previously unknown field of designing larger scale industrial machinery. The outcome is an overview of who Hydrema is and the needs and ambitions of the company in terms of development of a new concept design for an excavator.

Going native


ill. 1.1.1: The Hydrema machines are tested by the design groups

Production facilities


ill. 1.1.2: A welding robot controlling the process by itself.

Assembly


ill. 1.1.3: Assembly of an excavator done by two shy men.

Questions and answers


ill. 1.1.4: Thorkil Iversen explains about the many steps in their production.

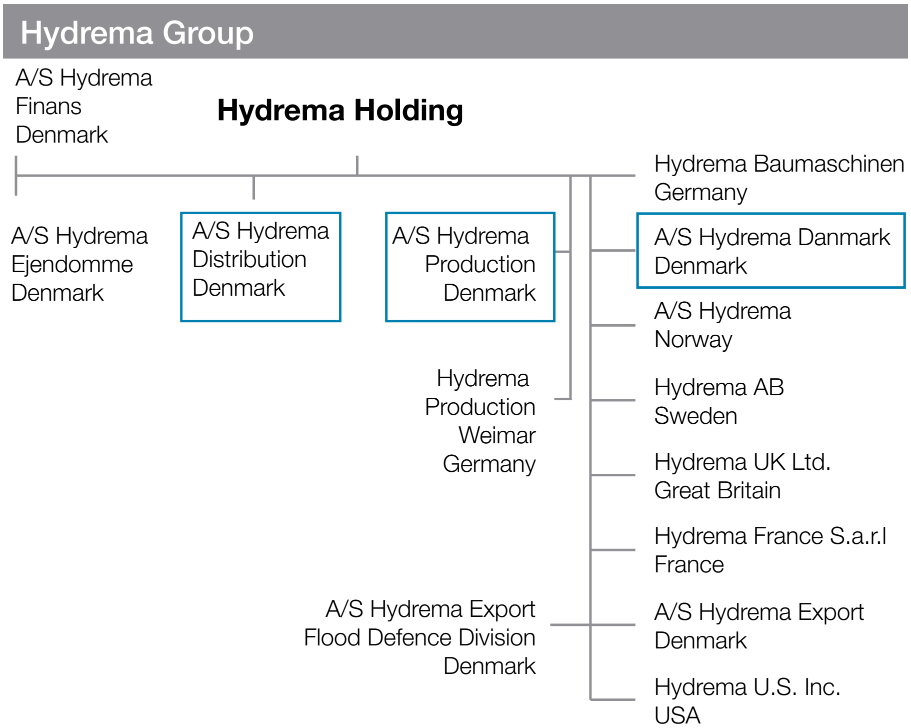
Hydrema profile

The chapter is a documentation of Hydrema through a SWOT analysis and an evaluation of their products, values, market and company structure.

Hydrema Group is an international concern founded in 1959. The company develops and produces high technology earth moving equipment for entrepreneur work and holds a handful of patents. Hydrema Group has a turnover of 700 million D.Kr. per year. The biggest considerations of the Hydrema Group are that the company needs to stand out in the big field of earth moving equipment manufacturers worldwide in order to survive as a smaller manufacturer in a large market.

Product portfolio

The product portfolio of the company covers high performance hydraulic entrepreneur machinery and material. Besides earthmoving machinery, mine clearing equipment and armored military excavators are in the portfolio.



ill. 1.1.5: Hydrema Group. The marked departments are the one's that the design group cooperates with.

Company mission

To offer moving equipment for the unique needs in the specific market. Flexible production facilities, innovative development and dynamic sales and marketing.

Weakness

Small production facilities
Identification of Hydrema products
Differentiating from competitors on machineprice

Strengh

High quality machinery
In-house development
In-house production
In-house marketing
Costumer understanding
Service policy

Company vision

To swim against the stream. A little fish among the big fish.

Opportunity

Military market
Alternative machines
Niche markets

Threat

Competitors
Dependent on “building boom”
Locked product architecture

Values

Hydrema is focusing at developing and producing products under the following key words:

- Trustworthy
- Efficient
- Worthwhile -professional appearance
- Comfortable
- Identity creating - soft values, image value
- Affecting - emotional bounding
- High resale value
- Technical solutions
- Low downtime
- Retail sale

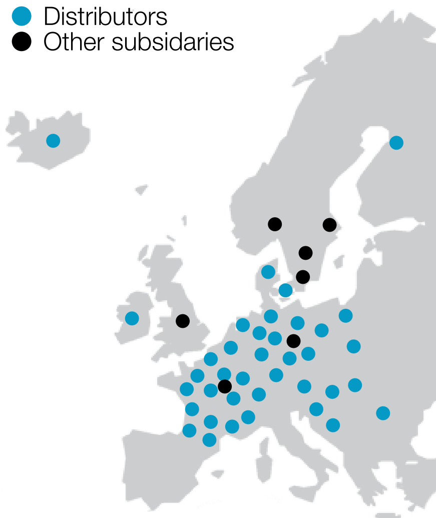
Market

Hydrema Group is one of the smaller concerns in the field of earthmoving equipment. The intentions of Hydrema Group is not to compete with big concerns such as Volvo and Hitachi but to target the product portfolio at a smaller part of the market; the market for wheel excavators. The main markets of the Hydrema Group are contractors, agriculture, industry and landscape gardening. The characteristics of the market of excavators is that it is a conservative market where only radical changes according to style, function and use has happened throughout the years. The functionality, reliability and performance capability is the main focus on the market and are the factors that are important to the buyers. [Hydrema 1st visit, appendix 4]

Company structure

The company has approximately 500 employees and controls a large network of sales and service facilities throughout Western Europe (ill. 1.1.6). Service in the rest of the world is taken care of by local dealers and importers. The company has a strong focus on the service in general and relies on close relationships with their buyers and operators to be able to improve their products. The production facilities are located in Støvring, Denmark and Weimar, Germany. The activities from developing an excavator to delivering the machine to the costumer are mostly in-house activities along with elements manufactured by sub-providers (engine and other components). All metal parts of the excavator besides the cast parts are produced in the production facilities of Hydrema.

Distribution



ill. 1.1.6: Europe distribution of excavators.

Outcome

Through the analysis of Hydrema, advantages and initial specifications for a new excavator are defined. The design group is aware of that it is an advantage and an opportunity for future Hydrema excavators to;

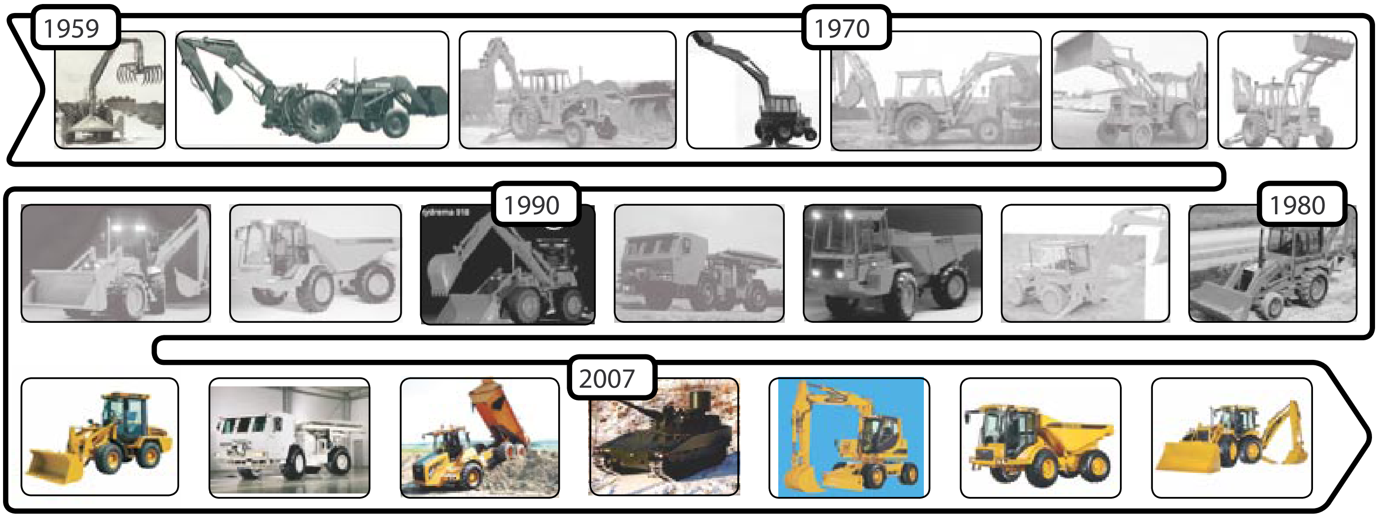
- Be produced in-house
- Be targeted at a new market niche
- Have a positioning value through functionality

Inhouse activities

ill. 1.1.7: Hydrema In-house activities.

Product portfolio

The Hydrema product portfolio is investigated according to style and history to be able to design a concept where their current products are considered.



ill. 1.2.1: A historical view of Hydrema products

Design history

Illustration 1.2.1 shows the history of Hydrema products. There is a clear development from very technical solutions to design solutions that express the functionality, but has softer lines and details that make the machines inviting and more humane. The excavator remains mainly a functional tool but the soft values and the image value of the excavator is becoming an increasingly important selling point of the excavator. [First visit Hydrema, appendix 4]

Characteristics

The characteristics of the Hydrema product line is:

- Hydrema logos
- Yellow/dark brown colors
- The rounded cabin
- Exposure of technical solutions
- Basic geometric elements/mixed shapes

Outcome

The exposure of functional elements and technical solutions are core elements in the style of the Hydrema excavator. The restrictions of the logo are to be considered when detailing the design.

When exploring and detailing concepts it is important to consider the existing Hydrema style and portfolio and how the product relates to the existing models.

Professional appearence

Robust expression.

Function easily read.

Exposure of functionality

Technical elements are highly visible.and express durability for heavy tasks

Identity creating

Curved lines

”Eyes”

Colors

Logo for identification

Comfortable

Curved lines

Softer and lighter expression

Integrated elements (frontlights)

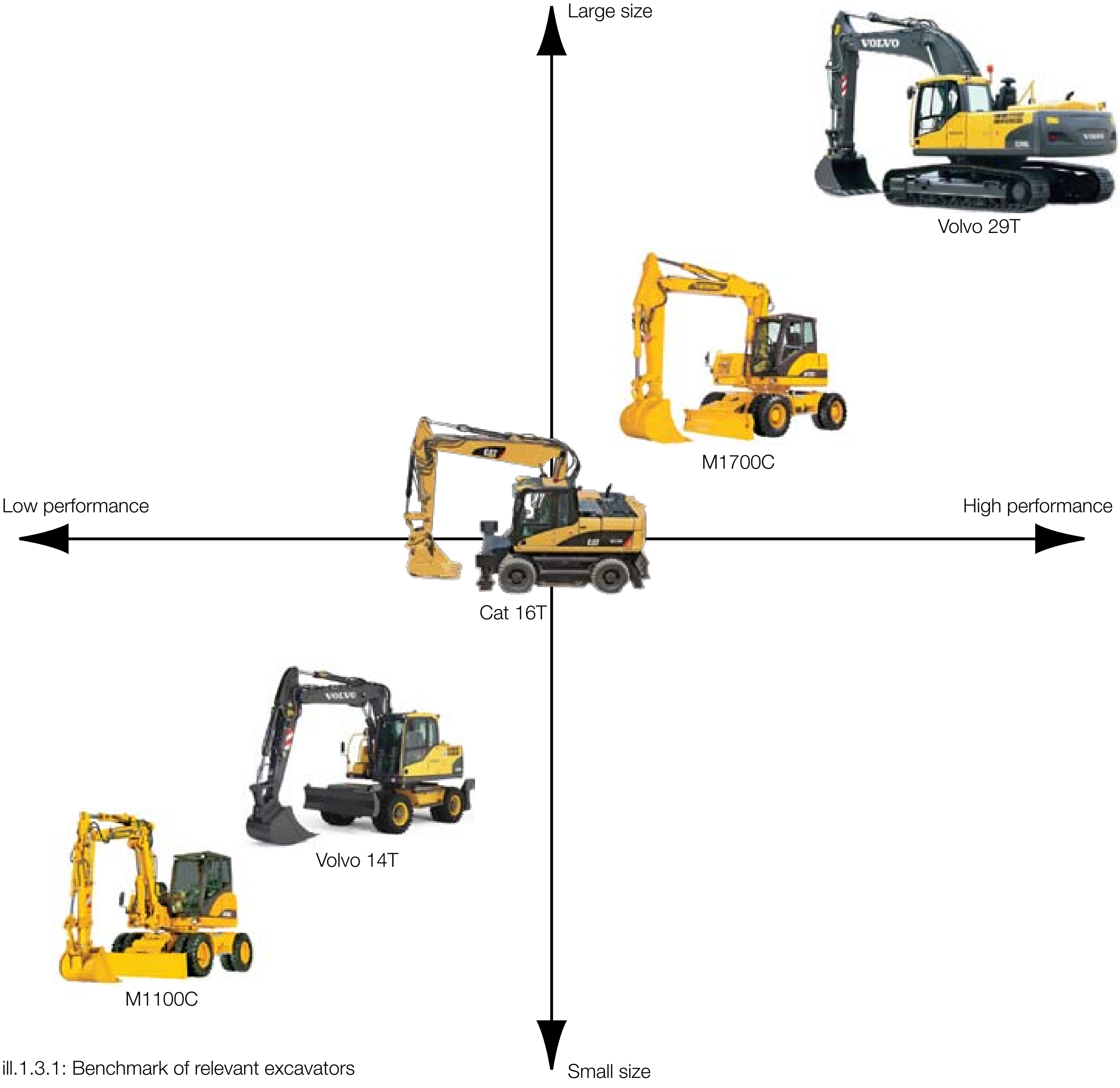
Cabin is marked by a black color, which makes it seem stronger

ill. 1.2.2: Hydrema M1700C excavator

HYDREMA

Market Registration

The excavators on the market are investigated to get an understanding of how they compare in terms of size, efficiency etc.



ill.1.3.1: Benchmark of relevant excavators

Registration results

The coordinate system (ill. 1.3.1) contains only a few models of the models that were investigated.

When comparing Hydrema excavators to machines from other companies, several things become clear. First of all the excavators from the different manufacturers do not differentiate a lot from each other. They use the same basic construction, stabilizers, type of arms, and similar engines etc.

One of the areas where the Hydrema wheel driven excavators do differentiate is in size. Several of their machines are very compact and able to work on very confined spaces (for example a one-lane road.)

As you move towards 18T vehicles, they become larger in dimensions and more efficient but less compact. Above 18T almost all excavators are tracked to distribute the load pressure but still they are not able to drive on-road because of size and regulations.

There is of course a difference in visual style and in detailing such as ergonomics which is one of the focus areas of Hydrema although this does not significantly differentiate them from the rest of the pack. The controls are very similar but the cabin comfort in terms of vibration and noise are also some of the main focus areas at Hydrema.

Inspiration

Other machinery from similar businesses (agriculture, tanks etc.) are studied to gain inspiration with a broader perspective on the subject, and are this way used for creating new principles to the concept for the excavator. Examples of these are the 8x8 trucks that participate in difficult off-road truck challenges (ill. 1.3.2), the Gradall excavator (ill. 1.3.3) which features a very different type of arm and tank and various experimental and real-world used military vehicles (ill. 1.3.4).

The products are used for inspiration in the creating of concepts for new excavation methods, propulsion systems and other aspects regarding the design.

Outcome

Hydrema has been focusing a lot on their M1400 and M1100 models regarding restyling and modification, and the group sees an opportunity to focus on the group of high performance models that are targeted at a market of high performance jobs, and much different than the compact models M1400 and M1100.

ill.1.3.2: Truck challenges

ill.1.3.3: Gradall excavator

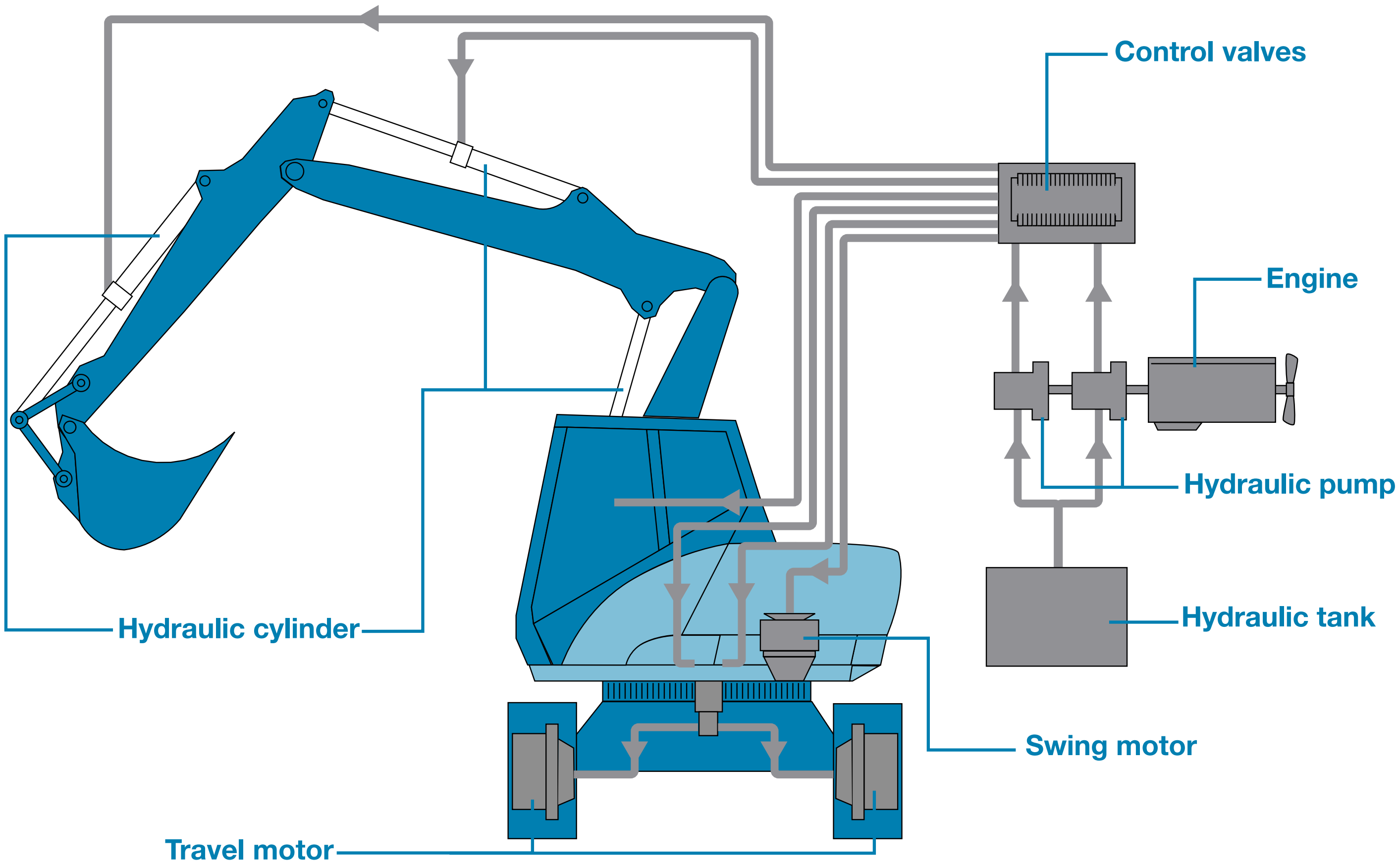
ill.1.3.4: WWII Tracked vehicle

Product architecture

The product architecture of the Hydrema excavator M1700C is analyzed to obtain an overview of technical solutions for reverse engineering when evaluating concepts.

The architecture of the excavator consists of mainly three parts; boom, upper carriage and undercarriage (ill. 1.4.1). Each part consists of several components which all have a certain function. The main components and their function is presented on the following pages.

ill. 1.4.1

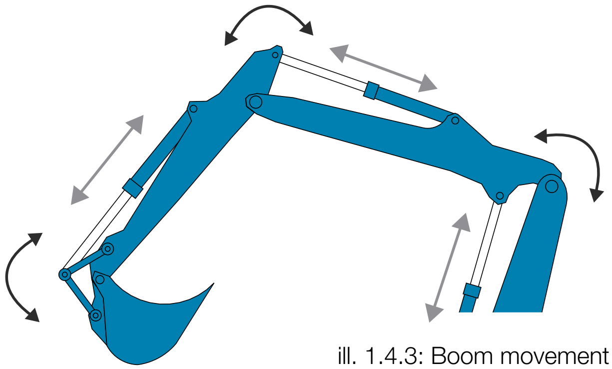


ill. 1.4.2: The product architecture of an excavator

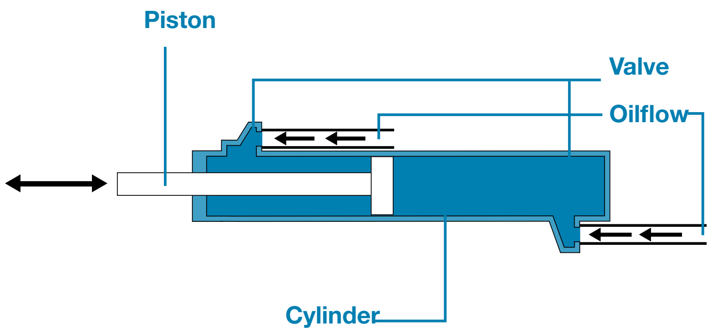
Upper carriage

The upper carriage contains the engine which provides the cylinders with sufficient oil pressure by powering a hydraulic pump. A counterweight is placed to secure stability when the excavator is working. The cabin is mounted on the upper carriage together with the boom. The whole upper carriage assembly can turn freely on the under carriage.

Ill. 1.4.2 shows how the engine transforms power into a hydraulic pressure and how the hydraulic elements of the excavator are placed and connected.



ill. 1.4.3: Boom movement

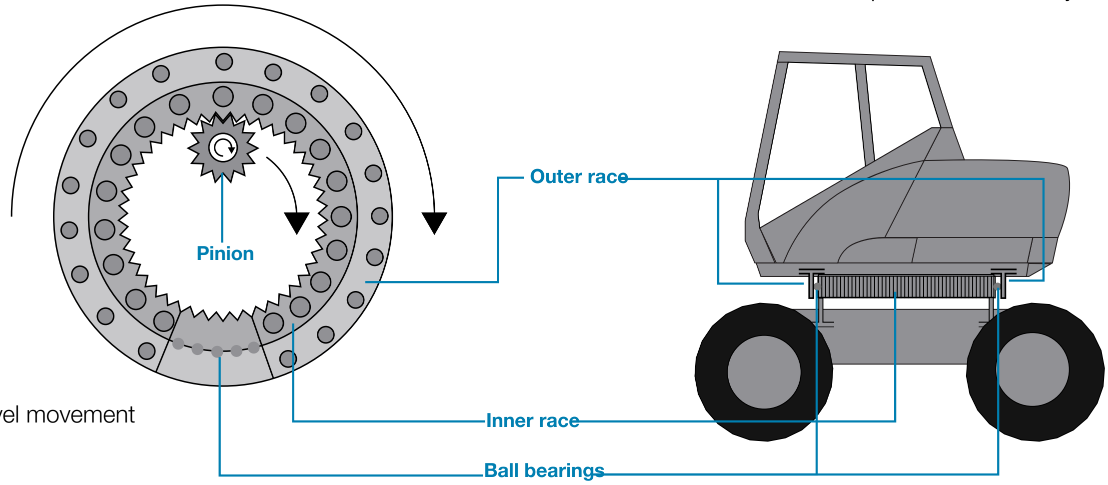


ill. 1.4.4: Piston movement

Boom

The boom (ill. 1.4.3) is attached to the upper carriage next to the cabin. Several tools can be mounted on the boom. The boom type can be a mono-boom or a 2-part boom. Motion of the boom is driven by hydraulic cylinders. The motion is limited by the pistons action and the boom structure.

Illustration 1.4.4 shows the basic mechanism for a hydraulic cylinder. The workload which the excavator can handle is dependent on the force the pistons and the oil pressure is in the cylinder.

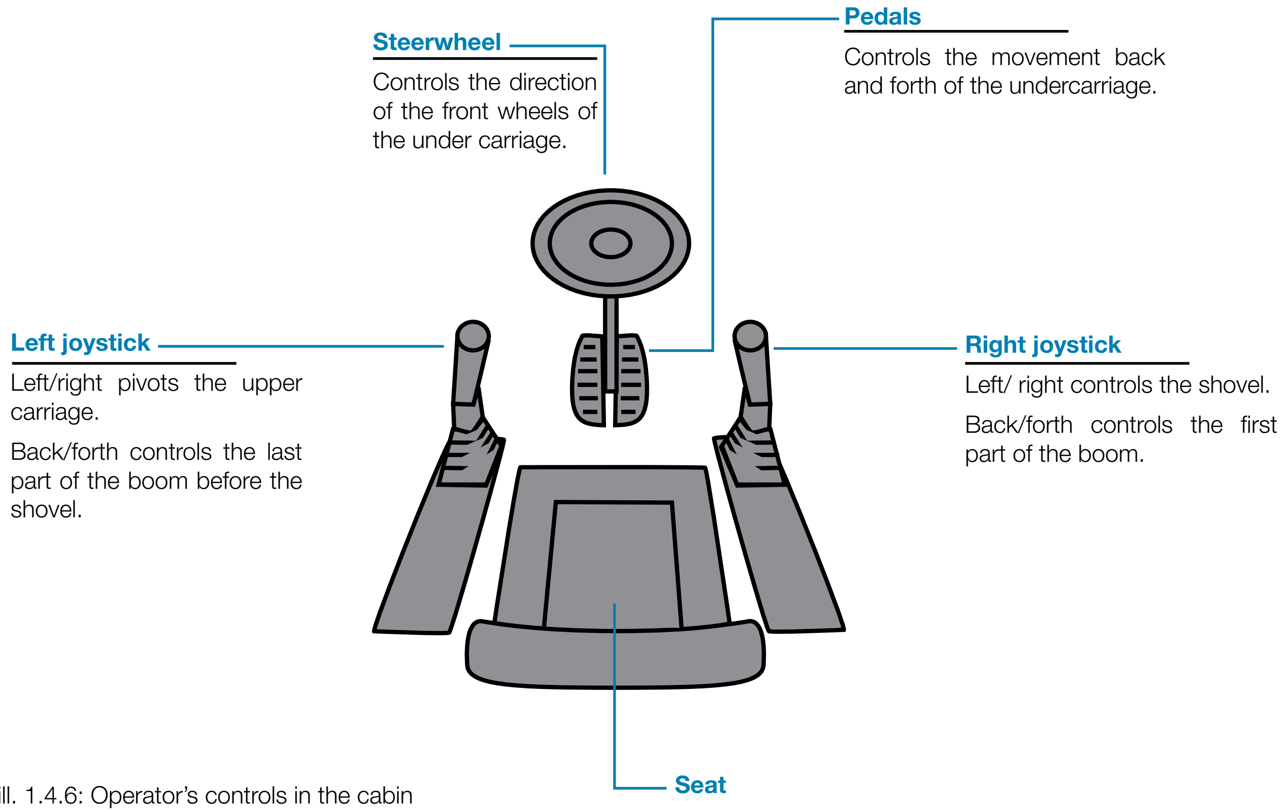


ill. 1.4.5: Swivel movement

Under carriage

The wheels or tracks are mounted on the under carriage to provide mobility to the excavator. They are propelled by hydraulics. Stabilizing equipment is mounted on the frame of the undercarriage. The undercarriage is connected to the upper carriage trough the swivel (ill. 1.4.5). This element enables the upper carriage to pivot 360 degrees independently of the undercarriage. Furthermore oil for the hydraulics in the under carriage is transferred trough the swivel, which makes this element highly complex. The complexity of this swivel rises as more hydraulic functions/channels are required.

Illustration 1.4.5 shows the function of the swivel. When the pinion, which is attached to the upper carriage, is pivoted around itself it moves along the inner race. The outer race then turns in the same direction as the pinion. The outer race is attached to the upper carriage and therefore forces this to move. The inner race is connected to the undercarriage and between the outer race and inner race, ball bearings are placed.



ill. 1.4.6: Operator's controls in the cabin

Cabin

The cabin is placed on the upper carriage next to the boom to ensure maximum view for the operator. The cabin protects the operator from dust, weather etc. and ensures comfort. Movement of the undercarriage, upper carriage, and boom is controlled from the cabin. See illustration 1.4.6.

Outcome

The excavator is a machine of high complexity and flexibility, which set up high demands for the product architecture, which has to be considered when designing the concept.

Context of use

The excavator is used for several tasks in a variety of surroundings. These surroundings are shortly introduced here.

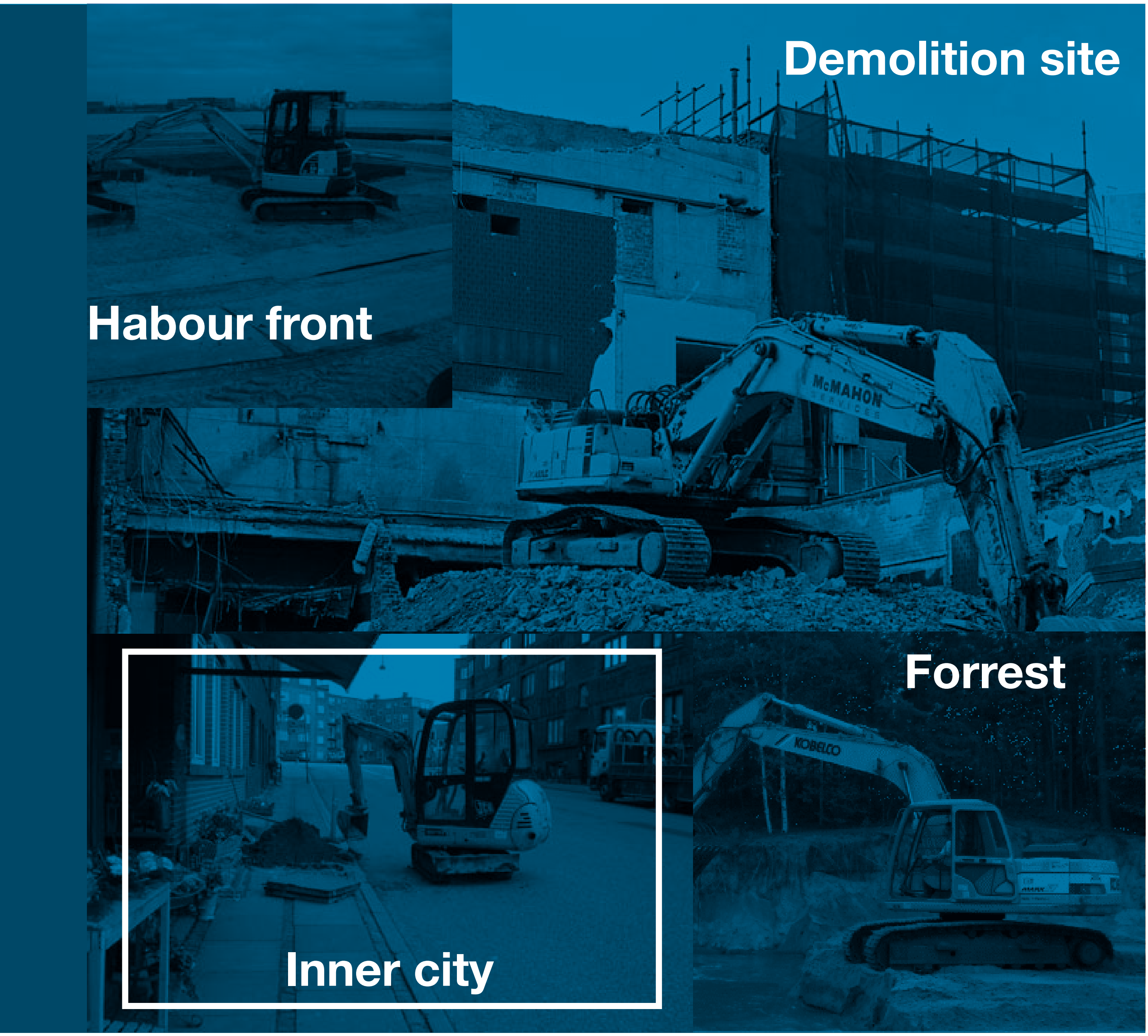
The design group initiate the project by exploring the tasks, use and context of the excavator.

The different tasks set up different demands to the flexibility of the excavator, the power, the stability and the mobility.

Outcome

After an initial research the design team focus at the use of an excavator in the inner city.

ill. 1.5.1: Excavators and their environment


Demolition site
McMAHON
SERVICES
Habour front
Forrest
KOBELCO
Inner city

Assignment

The content of the designbrief states the initial frame of the project. The following is concluded from the design brief.

The initial design criteria and aims within the different areas are through the process specified as the design group gets a deeper insight in the specific use and function of the excavator.

Client

Hydrema A/S, Støvring

Main assignment

To design a concept for an excavator for Hydrema A/S in the class of 14-17 ton.

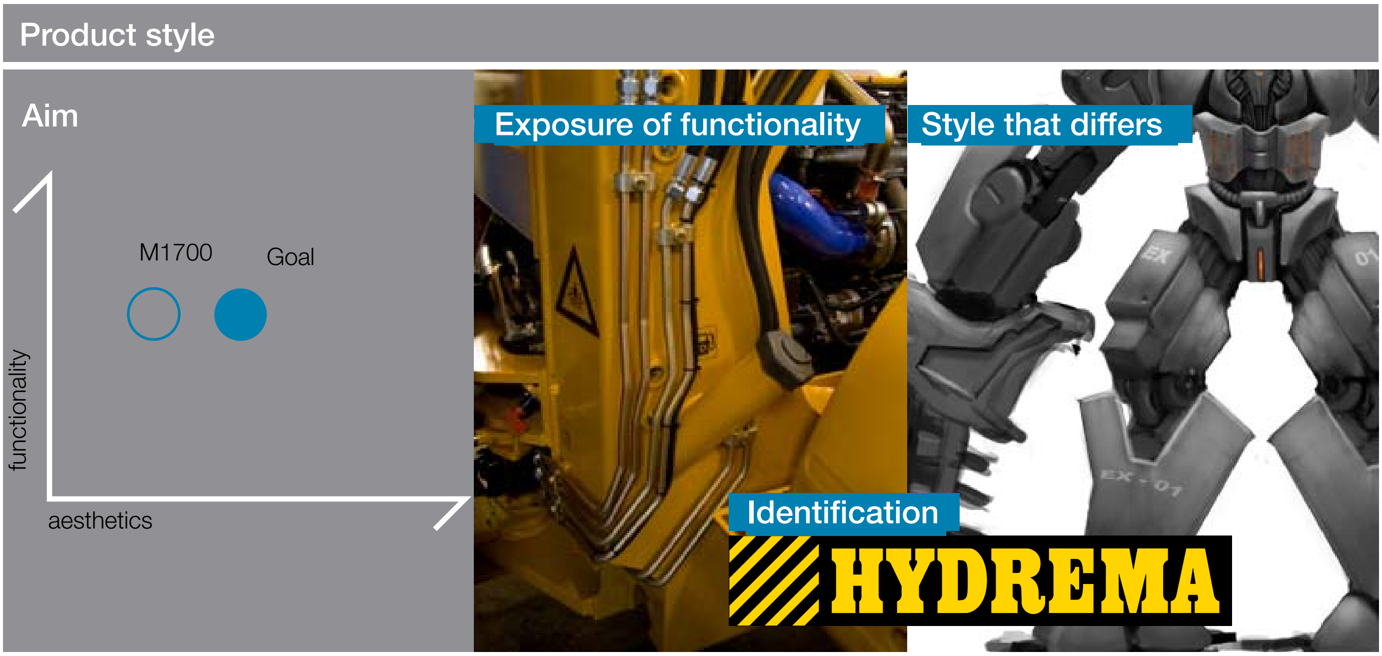
Design group interests

Mobility

Technics

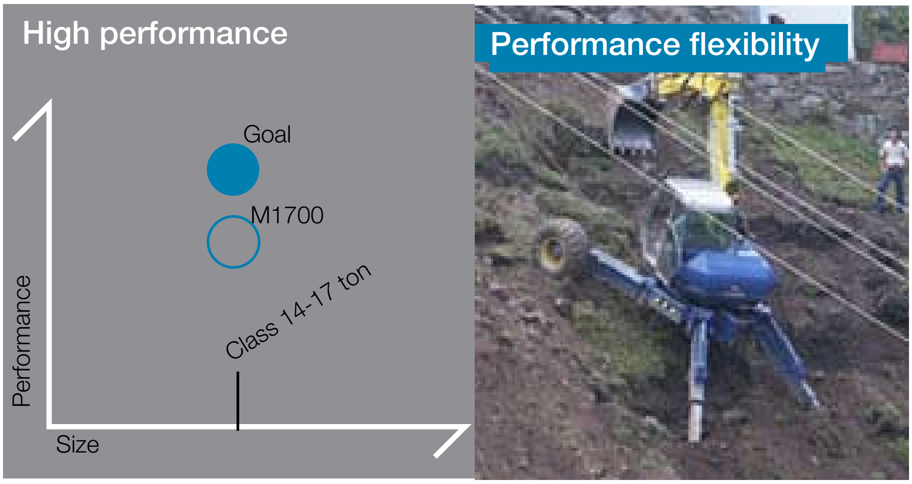
Design criteria

The three illustrations describes the initial approach to the product style, function and market of the excavator. These wishes for the product are throughout the process specified further and a final description of the specifications are made according to the model of Kano [Kano, 1984]. The criteria are described in the end of each chapter to give the reader an overview of the criteria that are handled in the next phase of the process.



ill. 1.6.1: Product style

Function



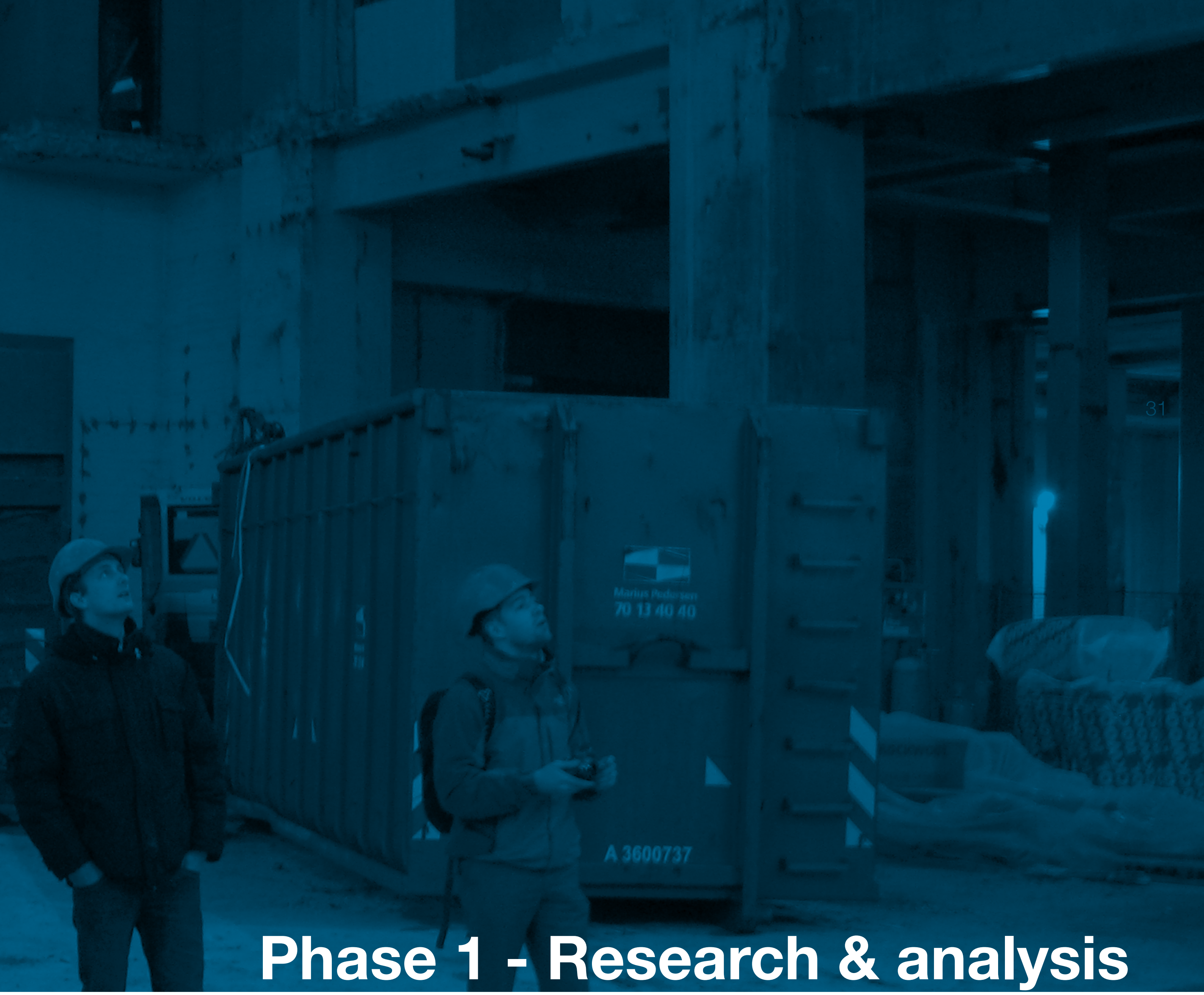
ill. 1.6.2: Function

Production

ill. 1.6.3: Production

Market

ill. 1.6.4: Market



Phase 1 - Research & analysis

Overview usecases - City

Sewers | Demolition | Foundation

Problem areas

Stability - terrain, load
Compact - power, dimension
Mobility - on/off road

Mission

Operator POV
Buyer POV

Vision

Hydrema POV
Design team POV

As a part of phase 1, the use and user research is inititalized.

The user based research clarifies problem areas observed in the city context. Based on the problems and the interests of Hydrema, a relevant market is defined and a vision and problem for the project is stated.

Research & analysis

As stated in the design brief the urban environment is chosen as context. The use and users of excavators are investigated.

The use of the excavators is observed to be able to determine problem areas and opportunities for improvement from the operator's point of view. The field areas are limited to Aalborg city because of good opportunities, for user research being readily available. Sites where the excavator is expected to perform different tasks are visited to broaden the perspective of the excavator tasks. Referring to the design brief special attention is paid to the on and off road abilities of the excavator. During the field observations the design group establishes contact to an excavator operator, Morten Viborg from IF. Nedbrydning. Morten Viborg and IF. Nedbrydning is used throughout the project to comment on problems and concepts. Further information and observations at the sites are documented in appendix 2-a, -b and -c.

Laying cables Kjærlundsvej in Aalborg inner city Functions: Digging trenches

ill. 1.7.1

Fragile sourroundings are damaged by the excavator when entering sites.

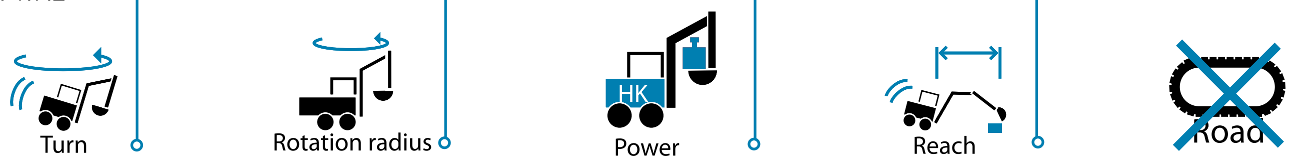
Power: The lifting power is limited by the counterweight and hydraulic power.

Reach: Lifting load while reaching far causes unstability.

Wear: The hard ground causes wear to rubber tracks.

Sewers
Forchhammersvej, Aalborg inner city. Functions: Digging trenches, Placing pipes, Placing framework, Leveling.

ill. 1.7.2



Turn: Unstability when turning and rotating with load.

Rotation radius: Large turning radius.

Power: High performance machine equals large dimension.

Reach: Stability when reaching far and digging deep.

Road: Iron track breaks pavement and roads.

Foundation
Harbourfront, Aalborg. Functions: Digging trenches, Lifting material, Leveling

ill. 1.7.3

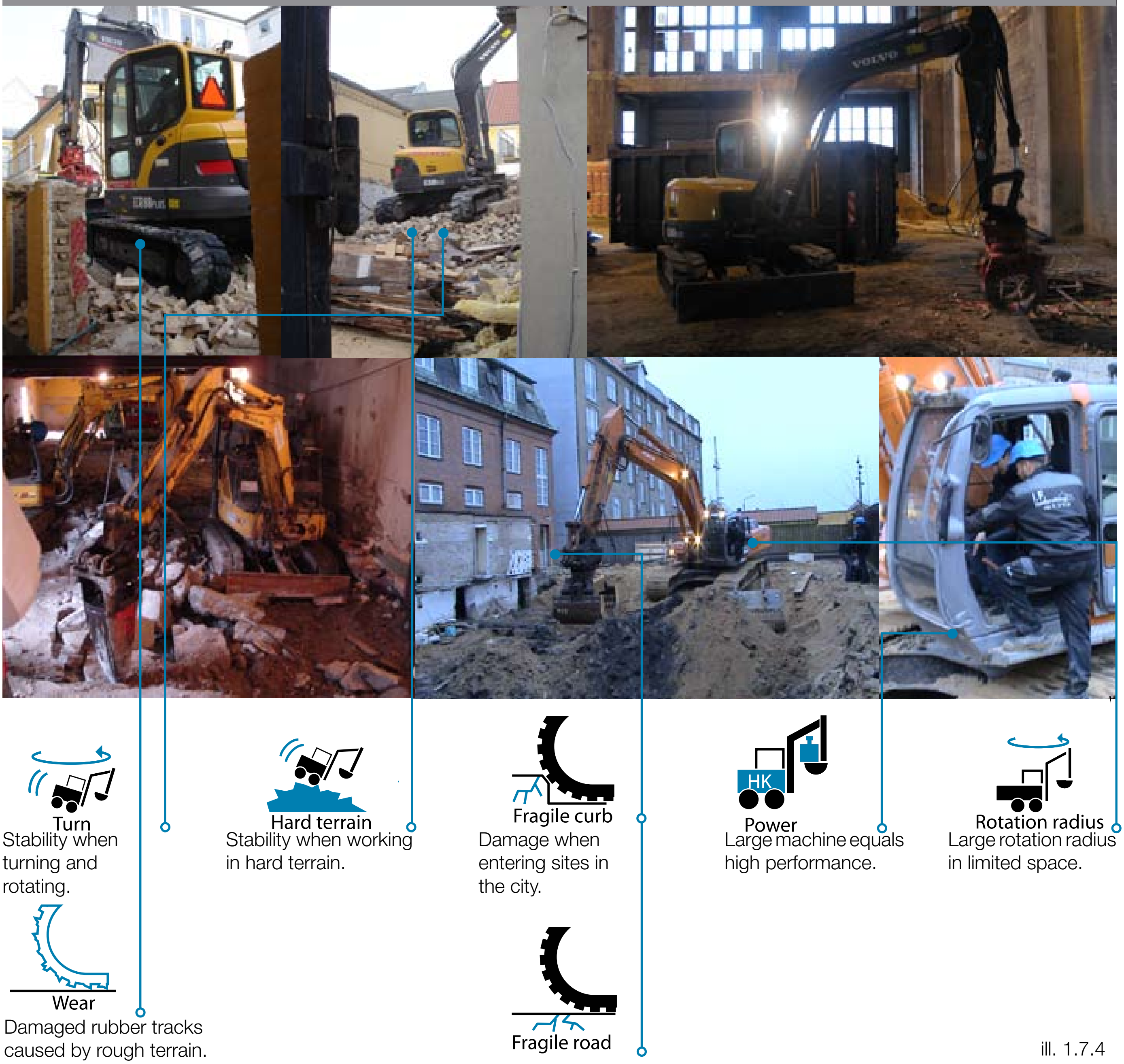
Reach: Stability when reaching far.

Soft terrain: Stability when moving and digging in soft terrain.

Manouevering without damaging the soft terrain.

Demolition

Context: Algade, Løkkegade, Nordkraft, Aalborg. Functions: Demolition, Crushing, Sorting material.



ill. 1.7.4

Problem areas

Based on the fields of use, the common problem areas are stated.

Through the observations it is clear that the problems at the site are common for city use of excavators.

The most common problem areas concern:

- Weight/power/dimensions
- Movement between public road and working site
- Stability when working off-road

Further it is pointed out for the design group when talking with several operators and contractors that the efficiency of the excavator in the city depends on physical dimensions, mobility on and off-road, weight and engine power. Common for the excavators is that large dimensions equal high performance and high efficiency. It means that if the context is suited for it, a high weight class is preferable for the construction/demolition team instead of a lower weight class.

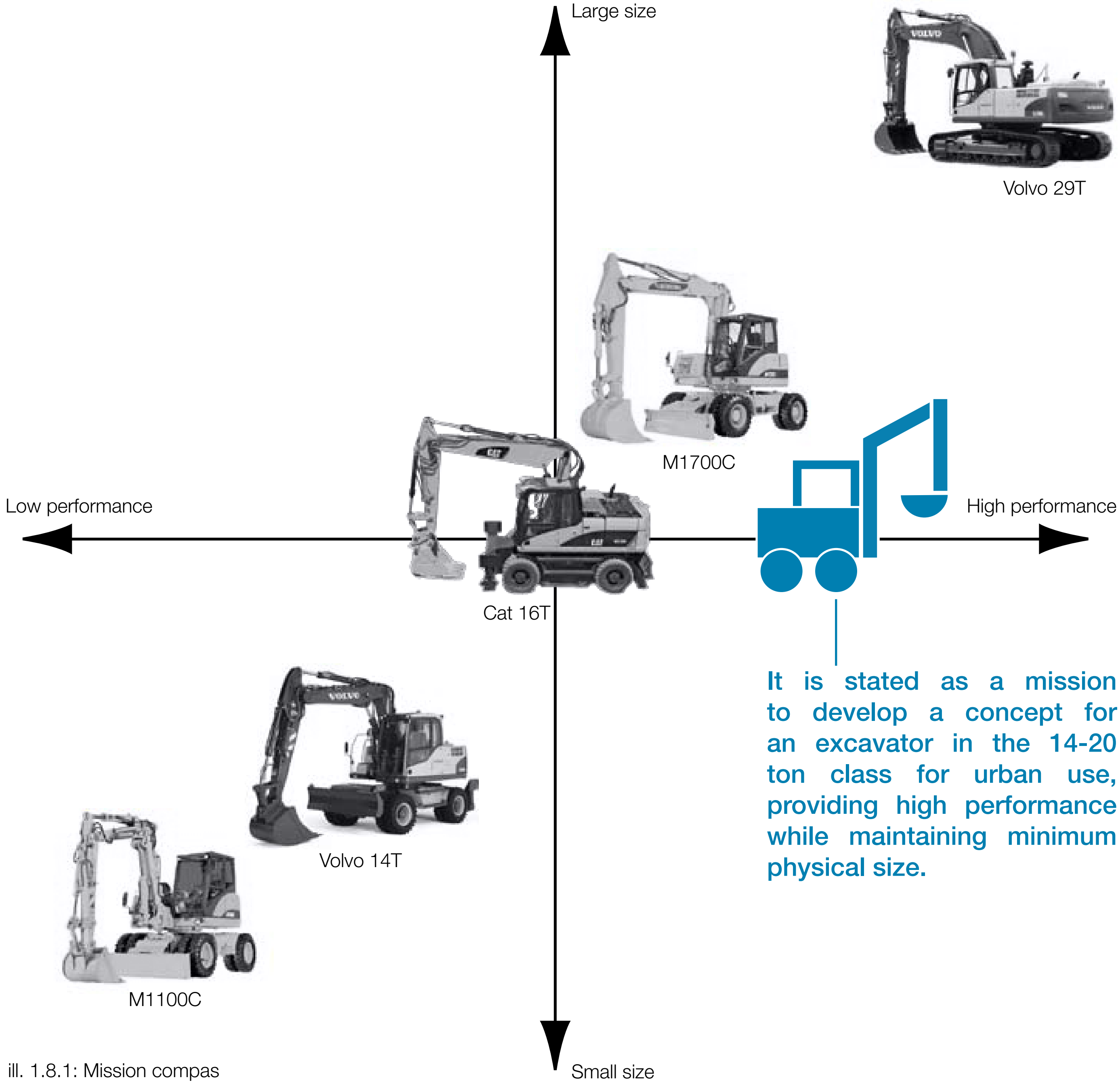
As observed at Nordkraft and Forchhammersvej in Aalborg, it results in demolition and construction teams during a job have to use different excavators because the efficiency of the low weight excavators are decreased through lifting capability and stability problems.

Outcome

The design group chooses the demolition site as design case based on the interesting problem areas concerning when large machinery has to enter narrow spaces in the city and having stability problems when the excavator has to handle large tools such as a hydraulic hammer. Further the case is chosen because the demolition market is found as an opportunity for Hydrema to enter a new niche. The approach will result in a concept that is more targeted at the demolition market than the Hydrema products are at this current stage. At the same time the approach does not exclude the current markets as construction sites, sewing and road work. The final solution will not necessarily be focused only at demolition, but will maybe appeal to other similar situations working with an excavator that are able to benefit from the same advantages.

Mission statement

The observations at the sites in Aalborg leads to following mission for a Hydrema excavator.

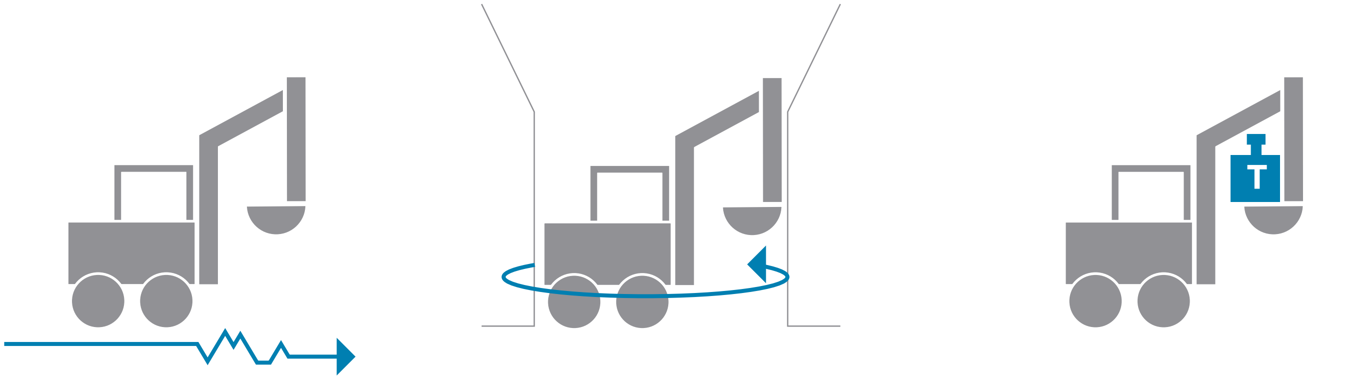


It is stated as a mission to develop a concept for an excavator in the 14-20 ton class for urban use, providing high performance while maintaining minimum physical size.

ill. 1.8.1: Mission compas

Vision

A vision is stated for fulfilling the mission statement. The vision describes the areas of focus when creating concepts.

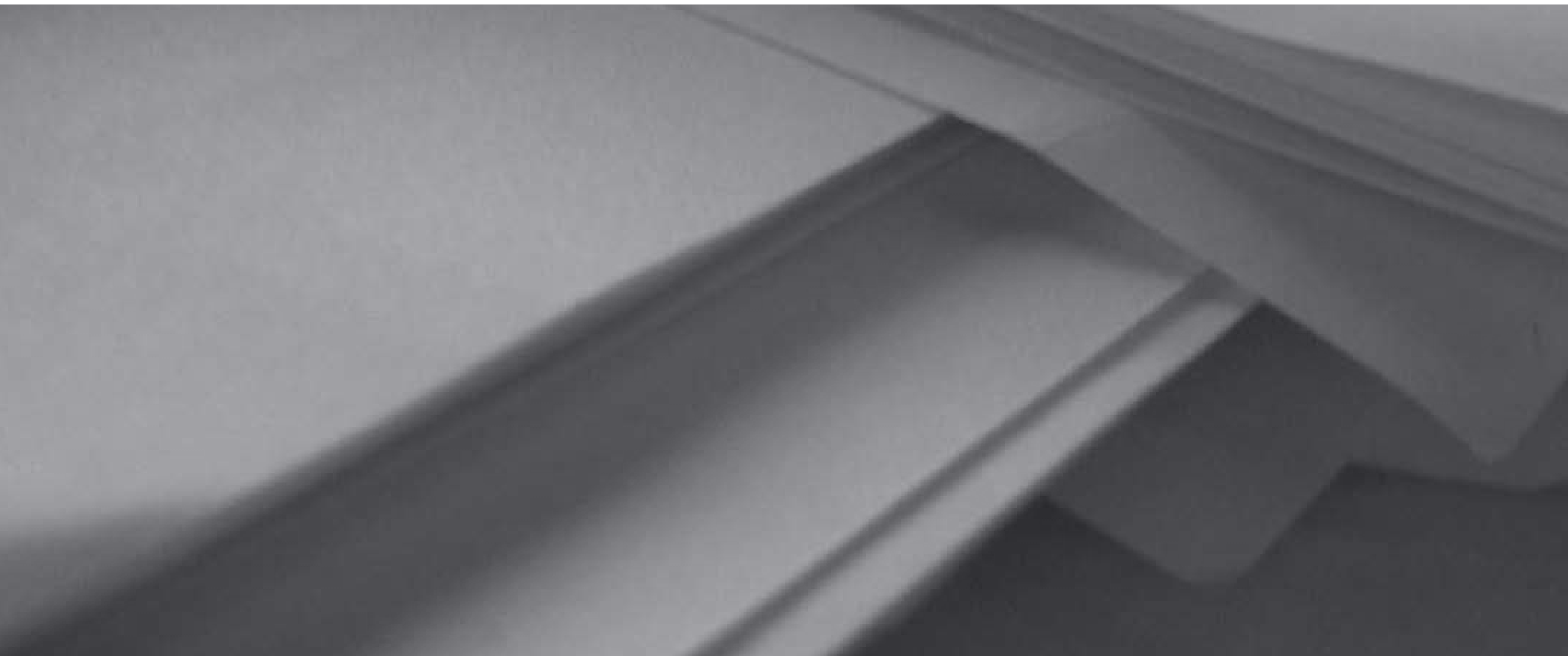


Increased on/off road mobility

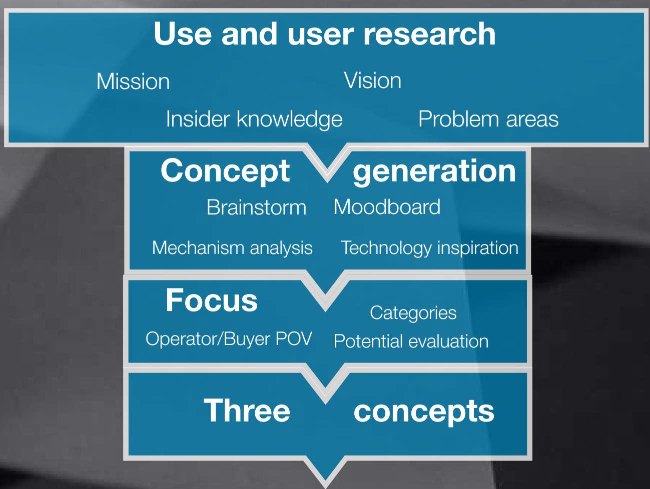
Size suited for urban context

Enhanced performance and power

ill. 1.9.1: Vision



Phase 2: Concept generation



Phase two deals with concept generation. Concepts are generated and the most promissing are selected and refined into three concepts. Inspiration for the concepts are taken in analysis of the usecases, cardesign and alternative mobility systems. The potential of the concepts is evaluated in collaboration with users. The final three concepts are presented for Hydrema in the end of the phase.

Creating principles

Parallel to the research and analysis, principles for excavator concepts are developed. The chapter describes the process of creating principles resulting in three excavator concepts.

As the research is carried out, the principles are becoming more specified according to the identified problems.

The ideas include everything from new conceptual excavators to simple add-ons.

They are documented as either sketches or notes, and saved in a pile to keep them for development when the main research is over.

The research cases are further analyzed according to mechanisms and functions and are used to identify the mechanisms of the excavator and the related jobs on the construction sites. [Appendix 2-a, -b and -c]

Based on the mechanisms, the group creates several categories some of which are:

- Boom
- Efficiency
- Dust control
- Stand-alone machine
- MMI
- Off-road

Generating ideas

The listed categories are then used to generate ideas for principles. The setup for coming up with these ideas is:

- 5 minute session pr. category
- Seats are shuffled between each session
- Ideas must be visualized
- Number of ideas rate higher than graphic quality
- Talk is allowed but the quality of an idea should not be questioned
- Ideas are placed in the middle of the table allowing the others to copy ideas or find inspiration

Sorting ideas

Afterwards the ideas are evaluated and sorted according to degree of potential; ok (almost final), potential (interesting principles, for inspiration and combination with others) and no-go (very low potential). [Sketching catalog, appendix 5]

At the time of sorting the ideas, the focus of the excavator is not yet decided. The vision is elaborated through further contact with Morten Viborg where problems and ideas for solutions are discussed. As the vision is specified to concern an increase in mobility, increase of compactness and an increase in performance the three concepts (ill. 2.1.2 – 2.1.7) are chosen to be further developed and presented at Hydrema.

Principles

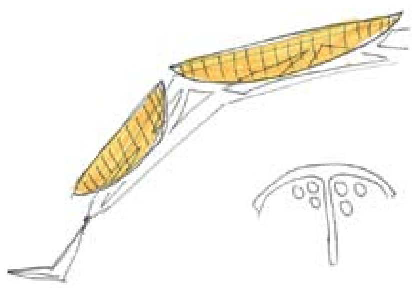
Even though the concepts are at an early stage it is decided to make the concepts appear as realistic as possible to give Hydrema a reasonable base for feedback.

The concepts each relate to the vision and mission but according to different functional principles:

- Skid steering
- Extendable
- Flip down
- Central axle controlled
- Three axles
- Light weight boom

Boom

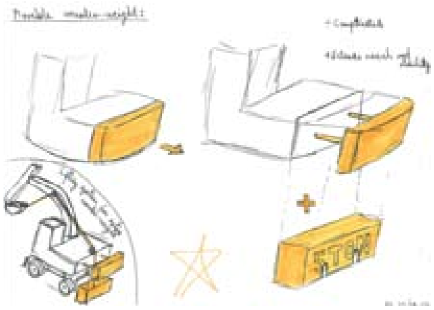
The intention according to the boom is to make it a lightweight construction using a lattice structure with a top plate protecting oil cables. The boom is considered for all three concepts.



Ill.2.1.1 Boom structure for the concepts.

1. Turning ratio and stability

ill. 2.1.2: Skid steering



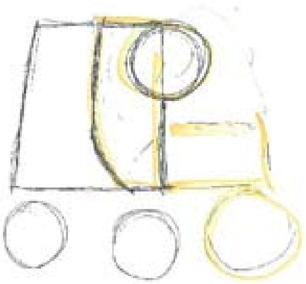
ill. 2.1.3: Expandable counterweight

This is a combination of the most realistic principles. The undercarriage is similar to the Hydrema M1700C excavator, but with the option to navigate using skid steering like tracks.

The counterweight should be able to stretch from the excavator to increase the performance through increased lifting power.

2. Off road/on road and stability

ill. 2.1.4: Flip-down tracks



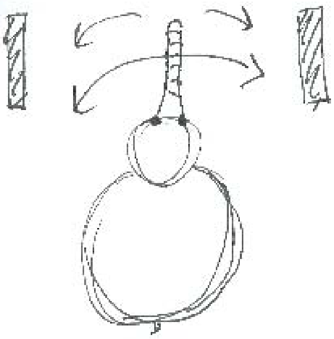
ill. 2.1.5: Expandable counterweight

This is a technical complex concept with 4 tracks capable of tilting to simulate wheels. This is implemented to enable the tracks to cause less friction and damage at fragile ground during transport and increased traction off-road.

The counterweight is a shelf that enables adding more weight using the demolished material from the site or other available material.

3. Ground stability and low rotation ratio

ill. 2.1.6: Six wheels



ill. 2.1.7: Counterweight ring

The intention for the concept is to stand out from the others, while dealing with the same areas. Six wheels give the excavator firm ground stability while maintaining good on-road capability. The engine is placed in the undercarriage to keep it closer to the ground and the only part rotating on the upper carriage is a ring containing the boom and counterweight.

Styling

Here the stylings of the three concepts are described. Before the rendering of the three final concepts, shape boards containing an independent visual style each are made.

The shape boards relate to the design criteria stated for the style in the design brief:

- A style that differs
- Exposure of functional elements
- Identification

To create a unique style that helps to identify their machines, Hydrema repeats various elements on the different machines. The most obvious element is the logo that must consist of both the symbol and name, and is often placed on the boom. The machines also have special yellow color that was designed especially for Hydrema and as a part of the upper carriage surface, the machines, at some locations, feature three offset stripes. (ill. 2.2.1)

To enhance a style that differs from the conservative common style on excavators, inspiration is taken in car design and military vehicles.

ill. 2.2.1: Hydrema’s three stripes

Shape board 1

For this concept it is decided to make a very edgy look. This is to refer to the old industrial machines and to underline the power that the machine holds.

ill. 2.2.2: Headlights and air intake of the Lamborghini Reventón

ill. 2.2.3: The design of the expansion mechanism of the Rinspeed Presto was used as inspiration for the counterweight.

ill. 2.2.4: Lines and screen of the Hummer Hx

Shape board 2

This concept is also based on an edgy look to refer to the power and old industrial machines, but without the tense dynamic lines of the first shape board.

ill. 2.2.5: The edgy and military back of the Warhog vehicle from Halo.

ill. 2.2.6: The heavy lines and shields of the Ford Bronco.

ill. 2.2.7: The clear opening mechanism of a concept vehicle from Starcraft.

Shape board 3

The last shape board is for a concept that is targeted at city use and is characterized by a small rotation ratio. To expose the function the style concerns round shapes.

ill. 2.2.8: The open view in a compact vehicle like the Courreges Zooop.

ill. 2.2.9: Cute and small with a more friendly expression. Jeep-Treo-Concept.

ill. 2.2.10: The Dodge M8's lines and curved screens with a round and more soft appearance.

Concepts

The concepts presented for Hydrema are described and evaluated from contractor, operator and Hydrema point of view.

Concept 1 - Expansio

The main idea of Expansio is to create a compact excavator with extended power and reach.

The purpose to create an excavator that can handle heavy tools such as a hydraulic hammer, which is essential at demolition sites.

Benefit contractor and operator

An expandable counterweight is useful at demolition sites because it allows the operator to enter sites where a smaller and lower performance machine normally would carry out the job. By using Expansio the contractor saves time and money because one machine can do the jobs of several (small or large) machines.

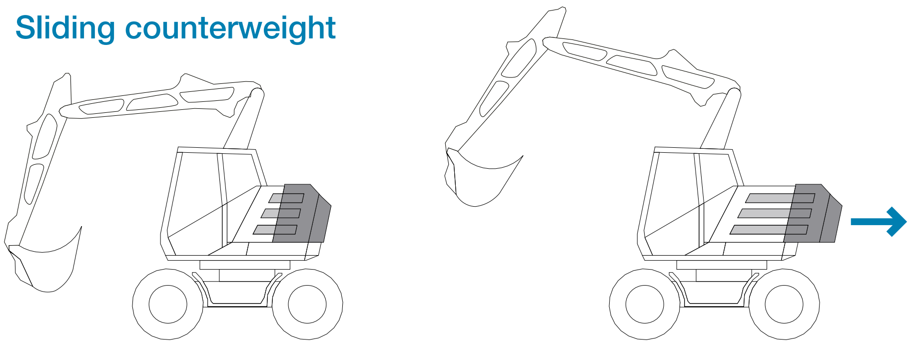
Benefit Hydrema

Hydrema benefits by being able to integrate a new feature into existing models and gain a presumably unique solution on the market; A compact excavator that fulfills the tasks of larger and less mobile excavators. Since Expansio undertakes the role of several excavators they are furthermore able to cut off some models in their product range.

See appendix 3.a for the full presentation

ill. 2.3.1: Expansio

Sliding counterweight



ill. 2.3.2: When the extra power is needed, expansio has the possibility of sliding the counterweight further back, hereby increasing the force available for the boom. Furthermore, the arm features a lightweight construction to decrease the weight in this area.

Concept 2 - mTrack

Like Expansio, mTrack is also a compact machine capable of delivering great power for the demolition sites. Instead of carrying around the ballast, mTrack has a counterweight system that allows extra weight to be added. It removes the load during transport and when it is not needed.

mTrack has a track system which is suited for driving on road as wheels and off road as tracks.

Having the features of the track off road also provide increased stability of the machine by having a greater surface for support.

Benefit contractor and operator

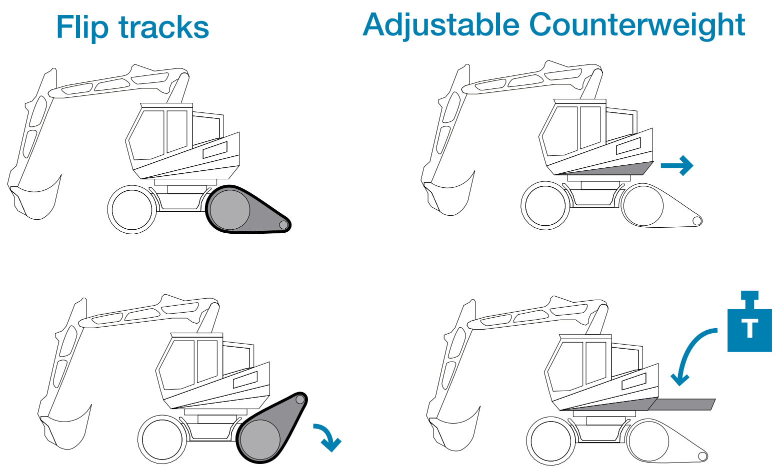
As Expansio, the possibility of extra ballast provides higher performance and reduces the need of two machines when a high performance machine can enter narrow places. Furthermore the excavator also has an improved off-road capability at the site, making it easier for the operator to maneuver hereby increasing the efficiency.

Benefit Hydrema

The concept does not compromise with the mobility value of the Hydrema products. Instead, the off-road capability is increased.

See appendix 3.a for the full presentation

ill. 2.3.3: mTrack



ill. 2.3.4: mTrack is a light machine that can add the weight needed to do a specific job. Furthermore mTrackhas flip-down tracks to increase the stability and off- road capability.

Concept 3 - Three-sixty

The idea of Three-sixty is to restructure the existing excavator in order to accomplish a similar machine where overview, mobility and stability are in focus. The upper carriage can rotate around a central axle and in order to improve the stability, the engine is placed in the undercarriage providing a lower point of gravity. The six wheels improve the traction in rough terrain.

Benefit contractor and operator

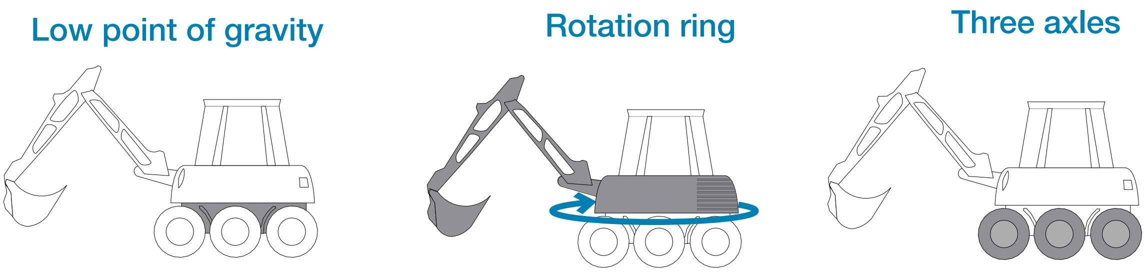
The round shape provides a low rotation ratio which increases efficiency of the work of the operator when working in narrow spaces. Also the six wheels provides stability in terrain. The benefit for the contractor is that the contractor saves transport expenses while the excavator can drive to the site.

Benefit Hydrema

Mobility systems consisting of wheels are a familiar technology for Hydrema, which means that the company can use existing resources and experience.

See appendix 3.a for the full presentation

ill.2.3.5: Three-sixty



ill. 2.3.6: Three-sixty is a restructured excavator, with a lower point of gravity and 3 set of wheels to increase the stability. The top part stands out by having only the arm/counterweight and the drivers seat/controls rotate when working with the machine, hereby reducing the amount of elements rotated.

Hydrema feedback

The following chapter describes the feedback from Hydrema.

The three excavator concepts are presented for Hydrema at the second visit. The positive and negative comments are listed.
See appendix 3.a for the full presentation.

Expansio

+ Sliding counter-weight
- Counterweight concept by O&K
- Too weak to be a whole concept
- Lightweight boom unrealistic

ill. 2.4.1: Expansio feedback

mTrack

+ Counterweight
+ Folding mechanism
+ Simplicity
+ Tracks
+ Possibility to keep current undercarriage
- Tracks only at the rear end

ill. 2.4.2: mTrack feedback

Three-sixty

+ The city expression
+ Six wheels
+ Inventiveness
- Complexity of rotation
- Little pay-off

ill. 2.4.3: Three-sixty feedback

Outcome

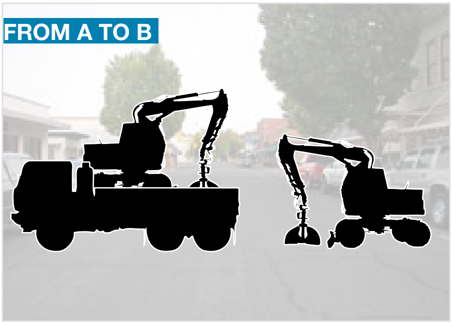
In general the feedback from Hydrema is positive and the concepts seem to have potential. It is mentioned that a similar counterweight as in Expansio is seen on a conceptual level by O&K. The design group has searched for the patent but it has not been found. Further it is pointed out that there are several complications with applying a trellis structure boom at an excavator because of stresses and strains when digging. Composite materials could be an option.

Hydrema showed special interest in the mobility principles and the simplicity of the flipping counterweight.

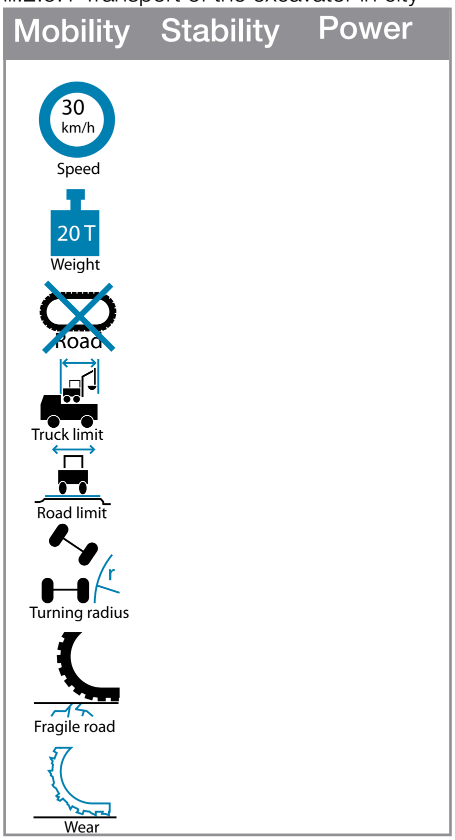
Design scenario

After the presentation at Hydrema a design scenario of the context and use of the excavator is made to get an overview of the potential of the principles included in the concepts.

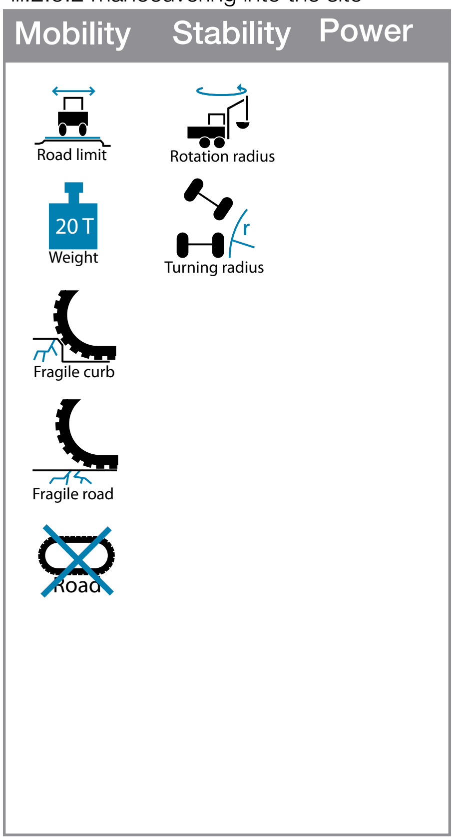
The presentation at Hydrema made it clear to the design group that the context, use and the specific problem areas according to demolition sites has to be made specific in order to be able to evaluate different solutions. The design scenario is based on use cases in Aalborg. [Appendix 2-a, -b, -c] The scenario describes the specific problem areas, pointed out as the icons, according to the vision of the project with specific focus at mobility and stability according to the interests of Hydrema.



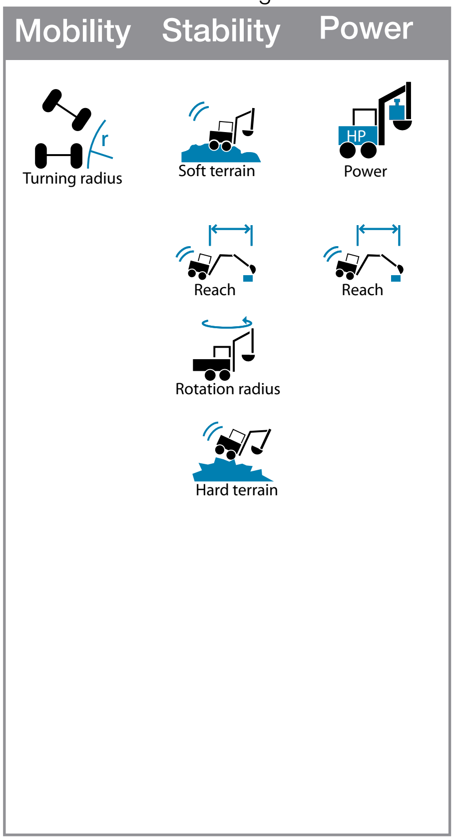
ill.2.5.1 Transport of the excavator in city



ill.2.5.2 manoeuvering into the site

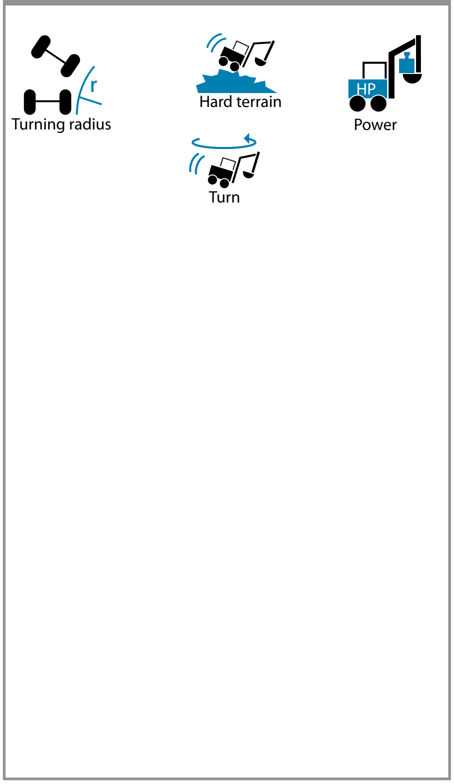


ill.2.5.3 Power demanding work on-site



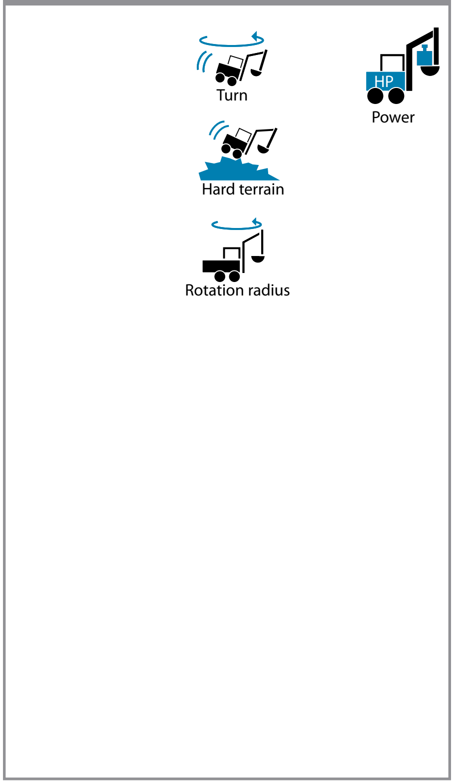
ill.2.5.4 Manoeuvre demanding work

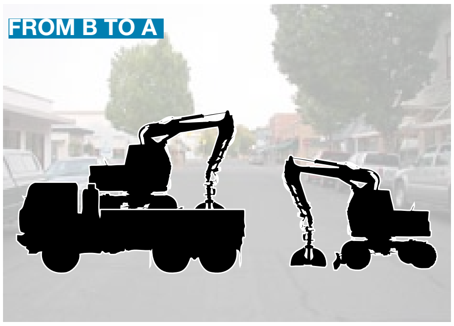
Mobility Stability Power



ill.2.5.5 manoeuvre demanding work

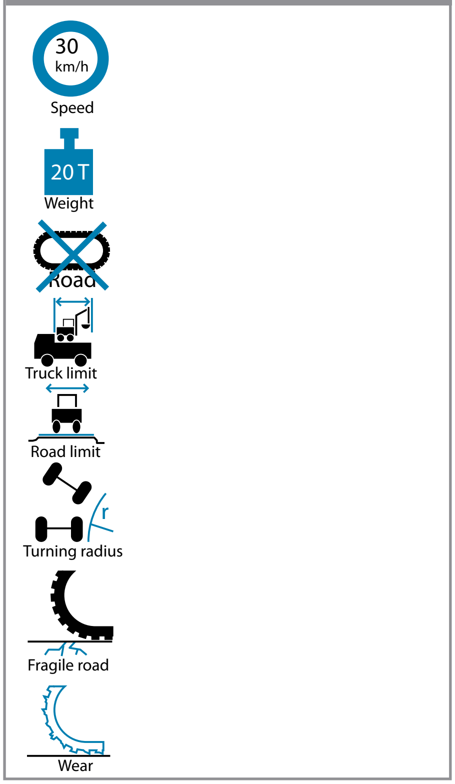
Mobility Stability Power





ill.2.5.6 Transport of the excavator in city

Mobility Stability Power



Focus areas

Based on the design scenario the problem areas are evaluated in the scale 1-5 (5 being the most important).

This is done to be able to focus at specific areas for improvement and set up design criteria for the concept.

The problem areas are converted to operator needs and metrics. Based on interviews with the operators in Aalborg, the learning objectives and interests of Hydrema five problems are chosen to be the focus areas. (ill. 2.6.1) The problems are specific for the inner city in situations where the excavator is driving:

- From truck to site (two times for each job)
- On/off site on bricks, road, sand (each day)

The highlighted problems (ill.2.6.1) are the areas that are evaluated as having the highest potential of being improved and developed according to fulfill the vision of the project.

Following topics state the focus areas:

- Entering site without damage
- Increasing excavator stability at the site
- Increasing lifting power

The areas are evaluated as a potential opportunities for Hydrema to differ their future excavators from other compact 14-17 ton excavators.

Problems	Operator needs	Metrics	Rating
20 T Weight	Vehicle weight and dimensions related to a specific task and context	Power/weight relation	4
30 km/h Speed	Follow traffic rules	Speed	3
Truck limit	Excavator that is portable when moving over large distances	Length/Width Weight	1
Road limit	Dimensions suited for narrow streets	Width	2
Turning radio	Manoevre in traffic Manoevre off road	Turning radius	3
Fragile road	**Suitable for driving on pavements and roads**	**Pressure Friction**	**4**
Fragile curb	**Suitable for driving over fragile obsticles**	**Pressure**	**5**
Wear	Low wear on roads and rough terrain	Friction	4
Hard terrain	**Hard terrain work, drive and manoevre capability**	**Friction Stability**	**5**
Soft terrain	**Soft terrain work, drive and manoevre capability**	**Friction Stability**	**4**
HK Power	**Lifting power related to load and tool.**	**Power/weight relation**	**5**
Reach	**Stability when reaching far or grabbing heavy load.**	**Weight distribution**	**4**
Rotation radius	Rotation on own axis in narrow spaces	Rotation radius	3
Turn	Stability when rotating upper carriage	Weight distribution	4

ill. 2.6.1

Stakeholders

The different stakeholders of the excavator and their interests regarding an excavator concept are discussed to be aware of the different points of view.

52 **Stakeholders**

Several people, companies or organizations have interests in the development of a new excavator. These interests range from mutual interests for all or numerous of the stakeholders to highly individual interests. Some interests from different stakeholders can even be in conflict with each other. It is therefore necessary to outline the stakeholders in a hierarchy of priority to be able to evaluate solutions for function, use and production, because it is difficult to fulfil all stakeholders' interests equally. The illustration 2.7.1 shows the hierarchy of stakeholders and their interests.

Stakeholders and interests

Design group
- Obtain learning objectives
- Realistic/concrete concept (within 2 years)
- Increase lifting power
- Optimize production (Hydrema)

Manufacturer (Hydrema A/S)
- Low investment costs
- Low production costs
- Profitable
- Multifunctionality
- Implementation in production
- Use of standard elements
- Identification/brand of values

Subsuppliers
- Use of the already excisting standard elements supplied to Hydrema

Buyer (Contractor)
- High reliablity
- Low maintenance cost
- Low buying price
- Low transport costs
- Performance efficiency
- Multifunctionality
- Off/On road manoeuvrebility

Operator
- High lifting power
- Multifunctionality
- Performance efficiency
- Stability when working
- Compactness
- Off/Onroad manoeuvrebility
- Comfort

Government / municipality
- Reduce pollution
- Reduce noise level
- Reduce dust
- Safety issues
- Respect of standards
- Respect of traffic rules
- Performance efficiency

ill. 2.7.1: Stakeholders

Hierarchy of interests

The stakeholders' interests are based upon observations, articles and interviews with the users. A hierarchy of interests is made in order to solve what kind of interests is the most important to fulfill. The hierarchy is based on user discussion with the operator, buyer and manufacturer. The list is therefore mainly covering their point of views. Furthermore the design group is also to consider as stakeholder of the project according to obtaining the learning objectives. The interests of the design group have first priority and even though the interest is founded in the process this highly affect the final solution for a concept. The hierarchy is not to be interpreted as absolute as there are some fundamental requirements that need to be fulfilled for it to be considered. For instance it does not matter if value is created for Hydrema, if value is not created for the customer as well. To keep the hierarchy and interests of the stakeholders realistic the concepts and partial solutions are presented to Hydrema and operator Morten Viborg, I.F. Nedbrydning in order to get feedback how they see their interests fulfilled. Ongoing meetings with the contractor from I.F. Nedbrydning have not been arranged and the interests of the buyer are partly stated by the design group and present interviews with contractors.

Hierarchy

- High lifting power
- Off/Onroad manoeuvrebility
- Performance efficiency
- Use of standardelements
- Implementat in production

ill. 2.7.3 - Hierarchy

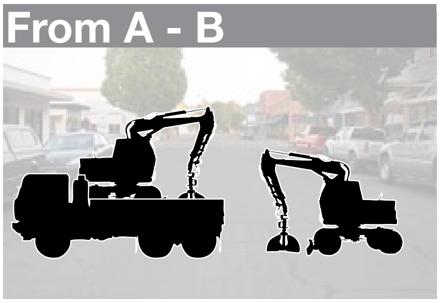
ill. 2.7.2: Morten Viborg

Focus

The resulting focus is briefly presented in terms of a use context, problemareas and current design criterias.

Design scenario

As a result of phase one, the design group choses to focus at three types of use of the excavator at a demolition site.



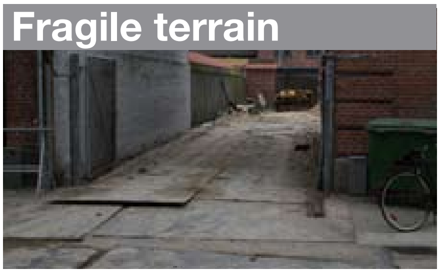
ill. 2.8.1: From A-B

ill. 2.8.2: Enter site

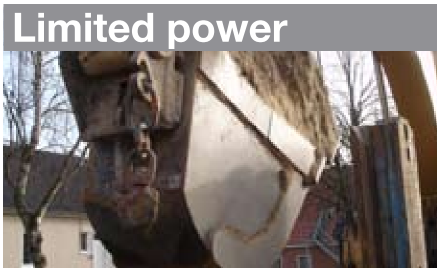
ill. 2.8.3: Demolition

Problemareas

Refering to the three types of use focus is on problems when entering site, manoeuvrering to and at the site and working with heavy tools.



ill. 2.8.4 & 2.8.5: Entering site



ill. 2.8.6 & 2.8.7: Power

ill. 2.8.8 & 2.8.9: Manoeuvre

Design criteria#1

The design criteria stated after analyzing the design scenario are further specified and arranged in an order referring to the hierachy of interests stated in the previous chapter. The functional principles to investigate further in phase 3 concerns the performance flexibility of the excavator. (ill. 2.8.10)

The focus of phase 3 is therefore the development of a flexible counterweight that can provide increased lifting power and an improved mobility system with better on and off-road capabilities.

Design criteria#1

Product style

Identification of Hydrema

A style that differientiate the product from the competitors within the market

Function

14-17 ton weight class

Ability to handle more heavy tools

Increase stability when excavator is working off-road

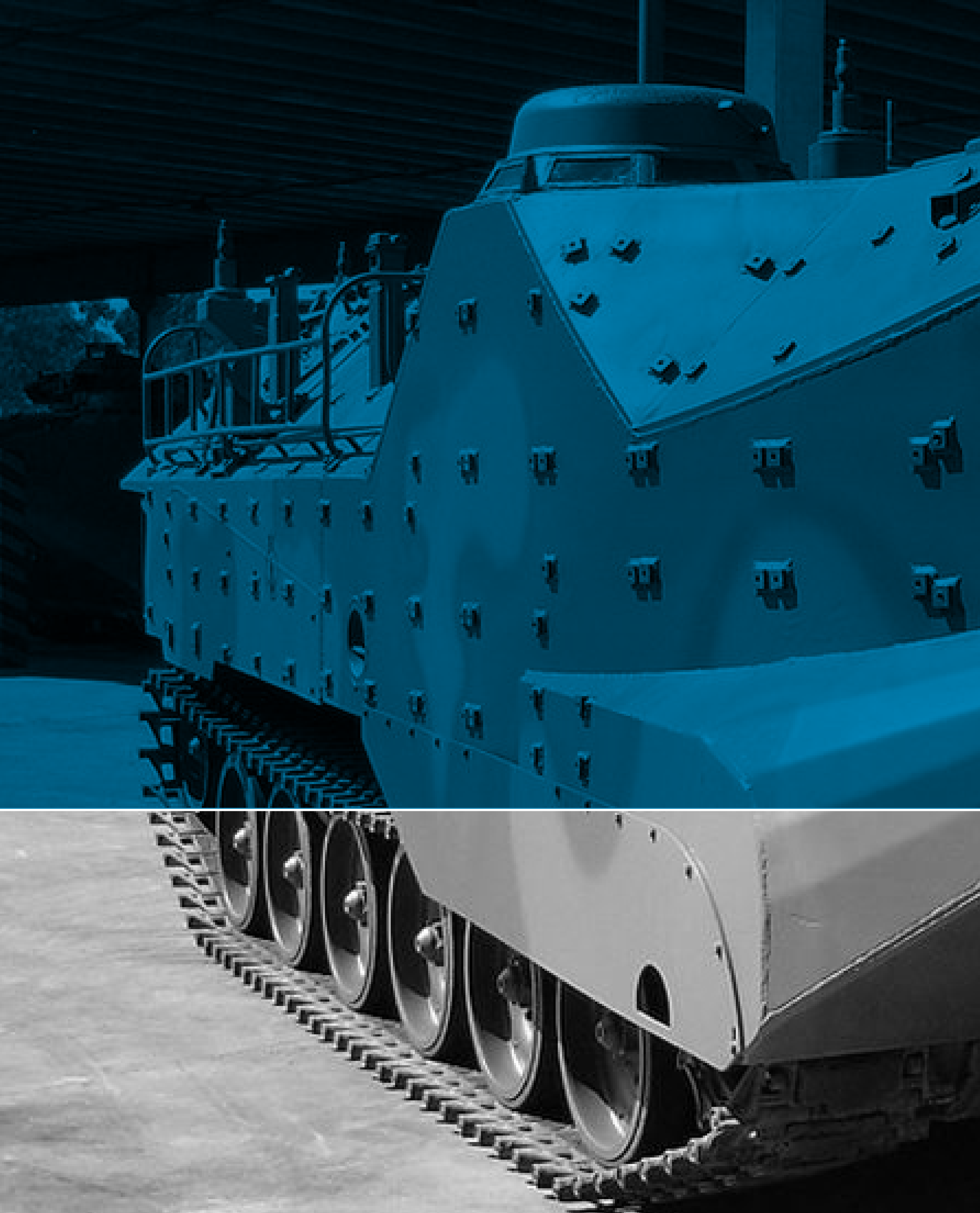
Increase off-road capabilities

Keep ability to drive on road

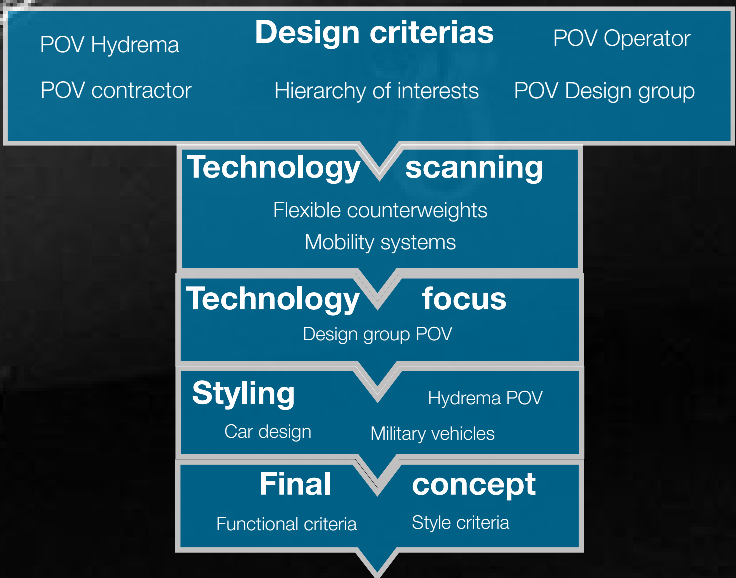
Lower the ground pressure of the excavator

Keep dimensions and weight in order to drive on road

ill. 2.8.10 - Design criteria#1



Phase 3: concept development



The concept development is initialized with the comments from the 2nd visit at Hydrema. To broaden the perspective of principles, technology scannings are made. Concepts are evaluated according to the learning objectives which makes the design group aware of which part of the excavator concept to detail. Based on learning objectives and a third meeting with Hydrema, two principles are selected for implementation in the excavator. The styling concept is framed and the phase is completed by a design concept integrating the principles ready for detailing.

Evaluating mobility systems

Different mobility systems are evaluated to be able to find a system suited for demolition sites in the city.

Evaluation

Existing mobility systems and conceptual systems are evaluated according to three parameters and according to level of inventiveness and the simplicity of the systems (ill.3.2.1). Systems are validated in relation to the main problems stated in phase 2. Afterwards systems are benchmarked to be able to find the solution with the greatest potential to meet the observed problems at demolition sites in the city.

Parameters

The systems are evaluated according to the parameters frame, work and terrain and variables within the parameters. (ill. 3.1.1) This is done to be able to validate the different systems according to the problem areas of the design scenario and hereby be aware of strong and weak aspects of the specific systems.

Frame

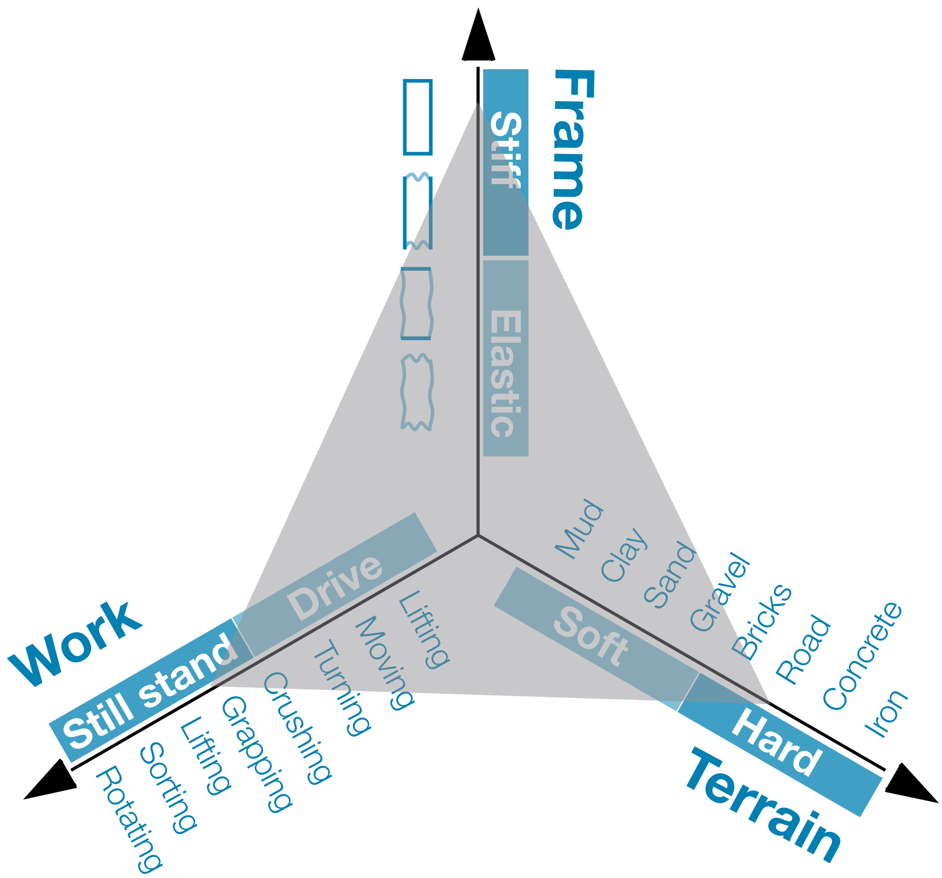
The stiffness of the frame is important according to the stability of the excavator when standing still working and moving on road. A stiff frame is better for working and an elastic frame is preferable when moving on road.

Terrain

Evaluating the mobility system according to the terrain is an important parameter when evaluating the durability and functionality of the system.

Work

Finally the type of work and the work positions are important to evaluate the system according to the specific use of the excavator.



Ill.3.1.1. The gray area illustrates the maping of the scenario example.

Example - Wheel system

Based on the settings, the different systems and technologies are benchmarked with one to five stars, where five stars is the best score. The example illustrated at the picture (ill. 3.1.3) and mapped in the illustration 3.1.2 shows one of a range of possible cases were the excavator is working in hard terrain. The excavator is standing still and the undercarriage is locked. According to the scenario, the mobility system has the following weak and strong aspects mapped at illustration 3.1.1.

Fragile road	Fragile curb	Wear	Soft terrain	Hard terrain	Turning radio	Simplicity	Level of inventiveness
★★★★★	★★★★	★★★★★	★	★★	★★	★★★★★	★

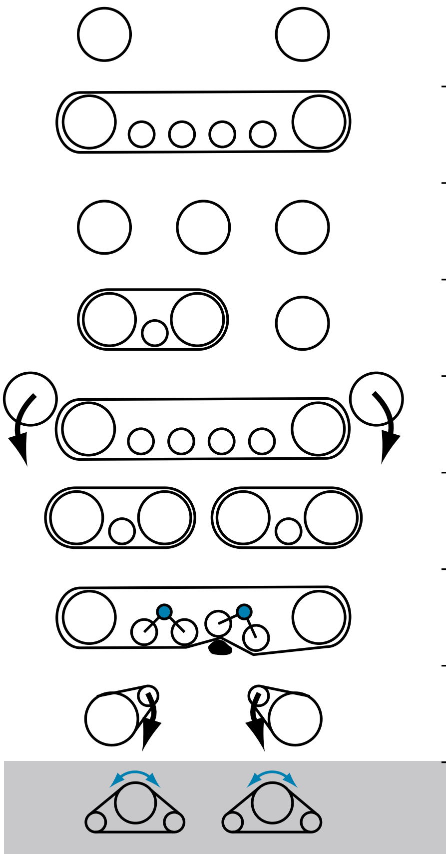
Ill.3.1.2: Grading of the wheelsystem.

Ill.3.1.3 Illustration of the scenario mapped in the diagram.

Technology scanning

The mobility systems are benchmarked according to the method explained in the previous chapter, to be able to compare the different solutions on the selected parameters.

Based on the evaluation method by Eskild Tjalve [Tjalve, 1976, p161] different technology solutions are compared and rated in a scheme to be able to compare abilities. The solutions are a combination of existing technologies and principles created by the design group in the initial sketching and existing systems found in online patent databases. Through the scheme the design group gets an overview of technologies based on principles from other machinery that are suited for the use and the context of en excavator at a demolition site. To be able to evaluate and understand the technology of the existing solutions, descriptions from providers and patents are used.



Technology	Fragile road	Fragile curb	Wear
Wheels	★★★★★	★★★★	★★★★★
Tracks	★	★	★
3+ axles	★★★	★★★★	★★★★
Half-track	★★★	★★★	★★★
Flip down wheels	★	★	★★
Multi-tracks	★★★	★★★	★★
Boogie wheels	★★	★★★	★★
Flip-down tracks	★★★	★★★★	★★★
Flexible 4-tracks	★★★★	★★★★★	★★★★

Outcome

The four-track mobility is chosen for further development as the system shows highest potential regarding solving the problem areas;

- Driving on road
- Entering site
- Stability/maneuverability off road

Soft terrain	Hard terrain	Turning radius	Simplicity	Level of inventiveness
★	★★	★★★★★	★★★★★	★
★★★★★	★★★★	★★	★★	★
★★★	★★★	★★	★★★★	★★
★★★★	★★★	★★★	★★	★★
★★★★★	★★★★	★	★	★★★★
★★★★	★★★★	★★★	★★	★★★
★★★★★	★★★★★	★★	★★★	★★
★★★★	★★★	★★★★	★★	★★★★★
★★★★	★★★★	★★★	★★★	★★★★

ill. 3.2.1 Benchmarking of mobility systems and technologies.

Project direction

To find the focus points in the project for detailing, the learning goals are considered.

At this point in the project, there is two possible directions for the project. The choice is between detailing the Counterweight or 4-track system. To get an overview of the possible directions for the project and how they fulfill the learning objectives, a chart is created (ill.3.3.1). To be able to fulfill all the objectives, the design group chooses to focus at detailing the flexible counterweight according to production, mounting, dimensions and vibrations. The flexible 4-track mobility system is still considered to be a part of the concept, but it is decided only to handle the tracks according to the implementation of the tracks to the excavator. This covers the mounting of the tracks, the styling of the excavator and how the tracks affect the performance of the excavator. The chart is converted to the specified learning objectives described in the approach chapter of the report.

Learning goals	Project area: 1st Visit Hydrema	Hydrema Profile	Hydrema SWOT	Market Registration	Hydrema Excavators Product Portfolio	Hydrema Excavator Product Architecture
1. Display an understanding of form and function, includes accounting for the relationshipbetween the whole and the details						●
2. Display knowledge of project management and production-oriented as well as marketorientedproduct development in practice	●	●	●	●	●	
3. Display knowledge of company culture and market culture	●	●	●	●	●	●
4. Display knowledge of technology scanning and market scanning as well as basic trendand competition analysis		●		●		
5. Display knowledge of incorporeal rights including patent protection						
6. Specify central elements such as technical details, kinematics, materials, surfaces,jointing etc. of a product						
7. Estimate the production cost of central components as well as the whole according toa given amount (including installation if relevant)						
8. Apply digital design principles; display knowledge of application in long distance collaborations between crossdisciplinary teams. Choice of software, file formats, settings etc.	●					
9. Display knowledge of the generation of product variance through reverse engineeringinterplay between physical and digital model				●	●	●
10. Carry out a Finite Element simulation of the subject and suggest variance and/orcomponent improvements based on a qualitative assessment of the result.						

Context of Use	Product Style	Usecase City	Problem Area	Initiating Problem Statement and Vision	Styling	Creating Principles	Creating Concepts	2nd Visit Hydrema	Design Scenario	Stakeholders and Target Group	Focus and criteria	Technology Overview	3rd Hydrema Visit	Hydrema Evaluation	Main Concept	Sketching	Dimensions	Construction Upper Carriage	Tracks Mountings on Undercarriage	Styling and Detailing	Logo and Branding	Production	Hinges	Mounting of pistons and Counter weight	Vibrations and Finite element on Counter Weight Profiles	Cost allocations	Business Strategy
	●				●	●	●	●				●			●	●	●	●	●	●	●	●	●	●			
●		●	●	●					●	●	●	●	●	●	●						●	●				●	●
●		●						●	●				●	●							●						●
										●		●	●	●								●				●	●
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																			●					●		●	
								●					●	●													
	●														●	●	●	●	●								
																									●		

ill. 3.3.1 Chart for learning objectives. The highlighted areas are the areas affected by the choice of concept development and detailing.

3rd Hydrema Visit

After the direction of the project is stated a meeting with Hydrema is arranged.

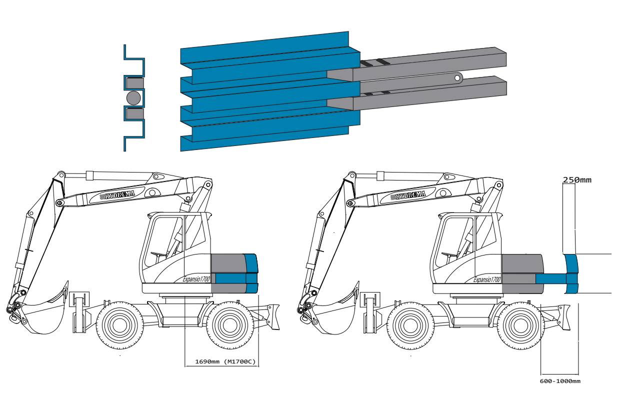
31st of March the group visits Hydrema to discuss and evaluate the result of the project development with the head of the Research and Development department, Thorkil Iversen and In-House designer, Tytte Hagen Johnsen. The design group mainly had three aims for the meeting:

- Insight in the complexity of producing a sliding counterweight
- Deeper insight in Hydrema's point of view regarding style
- Experience a "one-to-one" meeting with a company

See appendix 3-b for the presentation.

After the meeting it is clear that Hydrema will not produce a sliding counterweight because of the complexity of the sliding system. The complexity is due to the additional control of tolerances in the rail system that is complex to adjust. Further Hydrema has a great interest in simple technical solutions that can be produced in-house. This results in that the tip-down solution for a flexible counterweight (ill. 3.4.1) is discussed at the meeting and the solution is considered as a potential concept for the counterweight.

Counterweight rail Principle



The chosen counterweight system with rails for an off-set position will be complicated to produce, assembly and mount due to the fact that all the gliders must be casted and needs nylon enclosures to avoid backlash and make it possible to control the tolerances in the steel materials.

Thorkil Iversen

ill. 3.4.1

Developed Concept

The track-system is interesting and a good solution. Good that we can keep the on-road ability.

Tytte Hagen Johnson

Counterweight is good when integrated in the shape of the excavator.

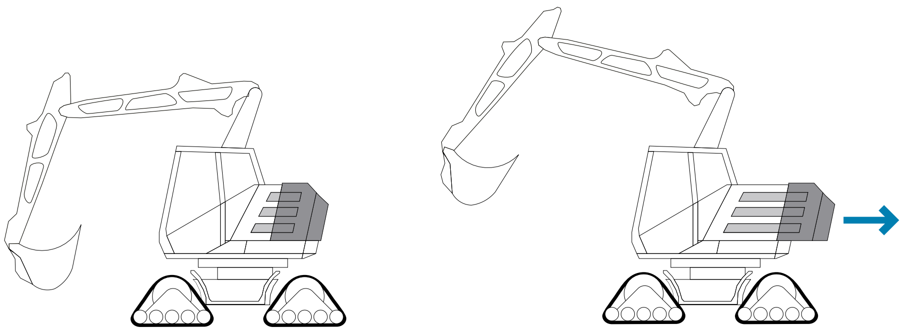
Thorkil Iversen

ill. 3.4.2

Outcome

After the meeting the design group decides to meet the wishes of Hydrema of a simple solution for the counterweight. This is decided based on the interests of the design group (pp. 50 - Stakeholders) of designing a solution that is possible to produce within realistic economic limitations. It does however provide some implications in relation to efficiency and visual appearance.

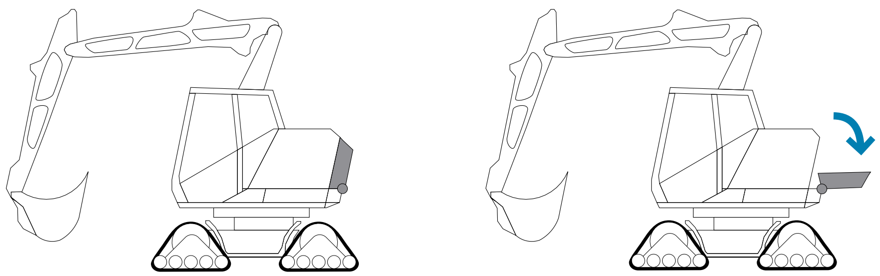
Sliding counterweight



Increase of lifting power	√
Visual coherence	√
Production	×
Assembly	×
Mounting	×

ill. 3.4.3: CW rail princple

Flipable counterweight



Increase of lifting power	√
Visual coherence	×
Production	√
Assembly	√
Mounting	√

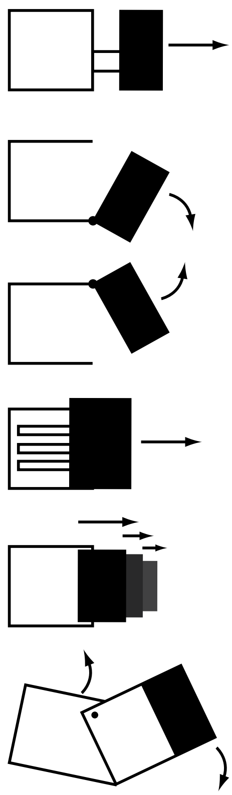
ill. 3.4.4: CW tip-down principle

Counterweight systems

Based on statements from the meeting with Hydrema, systems for a flexible counterweight are investigated and benchmarked.

Present principles for the counterweight are mapped in a scheme and graded according to the POV of Hydrema. The principles are evaluated on parameters referring to production, cost, efficiency and simplicity of implementation. This is done to ensure that the chosen solution has a strong cost/benefit relation for the manufacturer. Hereby it is made sure that the interests of the design group according to achieving a realistic concept are obtained. Further the principles are evaluated according to how they fulfill the problem areas described in the focus chapter of phase 2.

The illustrated principles in the scheme are a result of present sketches, new sketches made after the 3rd visit at Hydrema and existing conceptual solutions. For the sketches please see appendix 5.



Principle	Ease of implementation in productionline	Ease of production	Reliability
Slide displacement	★★★★	★★★★	★★★
Flip Down	★★★★★	★★★★★	★★★★★
Flip up	★★★★★	★★★★★	★★★★★
Displacement shell	★★★	★★★	★★
Displacement Babushka	★★	★	★★
Scissor system	★	★★	★★

Ill. 3.5.1: Scheme of principles for the counterweight.

Outcome

The result of the evaluation is that the principle with a flip-down counter-weight is the solution with the greatest potential according to production aspects. Also the solution is evaluated to have the highest potential in relation to the learning objectives of the design group in terms of converting the principle to a manageable system for further development and detailing.

Cost	Implementa-tion in form	Effect
★ ★ ★ ★	★ ★ ★ ★	★ ★ ★ ★ ★
★ ★ ★ ★ ★	★ ★ ★	★ ★ ★
★ ★ ★ ★ ★	★ ★ ★	★ ★ ★
★ ★ ★	★ ★ ★	★ ★ ★ ★ ★
★	★	★
★	★	★ ★

Concept principles

The results of the concept generation are briefly presented in the following in terms of a use context, problemareas and current design criterias.

Style inspiration

ill. 3.6.1: F-117 Nighthawk

ill. 3.6.2: Lamborghini Reventón

Based on previous moodboards where inspiration is taken in military vehicles and car design, a moodboard is made for the final concept. The rough and aggressive style is chosen to relate to the context of use and the performance of the excavator.

Gain

- The intention is as stated in the assignment; a style that differs from competitors and former Hydrema products.

Track system

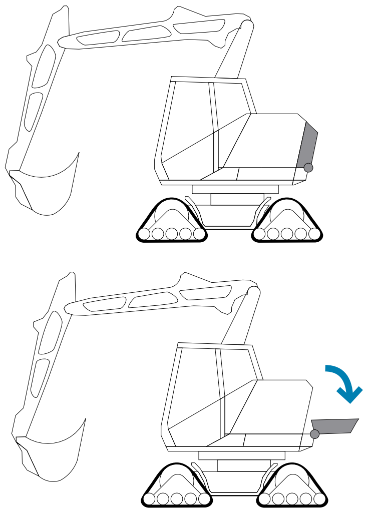
ill. 3.6.3: John Deere 764 HSD

The excavator concept includes a four track system based on existing technology.

Gain

- Increased off road capability while maintaining onroad capability
- Improved stability

Flexible counterweight



ill. 3.6.4 Tip-down principle

The main feature of the excavator concept is the flexible counterweight.

Gain

- Increased lifting power by same size of machine
- Can do the job of different sized machines
- Stability off road when working
- Flexibility in terms of use of tools

Design criteria#2

The design criteria#2 are based on the design criteria#1, but developed by a further detailing of the areas.

These criteria are used as guidinglines in phase 3, for what must be achieved regarding the development of the excavator as a whole.

The outcome of the following phase 3 is a rendering of the concept in a quality that can be presented at the final presentation at Hydrema.

Design criteria #1

Product style

Identification of Hydrema

A style that differientiate the product from the competitors within the market

Function

14-17 ton weight class

Ability to handle more heavy tools

Increase stability when excavator is working off-road

Increase off-road capabilities

Keep ability to drive on road

Lower the ground pressure of the excavator

Keep dimensions and weight in order to drive on road

ill. 3.6.5 - Design criteria#1

Design criteria #2

Product style

Identification of Hydrema within the styling and graphic

Exposure of functional elements

Overall style with inspiration from stealth. (ill. 3.6.1 & 3.6.2)

Overall dimensions

Weight class 17 Ton

Max. Height 3900 mm

Same width as existing M1700C model from Hydrema Width: 2500 mm

Same length of upper carriage as M1700C model: 2700 mm

Max.Weigth 18 ton

Elements

Same boom as used on the M1700C

Same internal elements as M1700C and placement (-counterweight)

Function

Increase of stability using counterweight and 4 track system.

Placement of counterweigth with min. influence on internal elements

Use existing undercarriage from M1700C with modifications to fit a 4-track system and achieve the desired expression.

Function - Counterweight

Increase lifting capacity using a moveable counterweight

Min. 20 % increased lifting capacity when uppercariage is positioned parallel with undercarriage

Min 25 % increased lifting capacity when uppercarriage is positioned perpendicular to the undercarriage

Placement of counterweigth with min. influence on internal elements

Production

Optimization of expenses for counterweigth production

ill. 3.6.6 - Design criteria#2

Styling principles

A set of styling principles are set up for the styling of the excavator concept.

Besides the design criteria and styling principles, the product architecture is also considered based on the dimensions and elements of the Hydrema M1700C excavator [Appendix 9].

The design group is especially aware of integrating the tracks as well as the counter-weight (contracted and expanded) in the final shape. Introducing new objects to the shape set up some new problems and requirements for integrating the new elements in the visual expression of the excavator.

Focus

The focus of the styling is to create a relation between tracks and undercarriage as well as counterweight and upper carriage through continuous lines.

Methods and tools

The basic methods for the session are hand sketching, Adobe Illustrator drawings and Solid Works 3d-modeling. The styling concept (ill. 3.7.1) is the result of the initial session. The further development of the styling is illustrated at ill. 3.7.2 - ill. 3.7.3. The styling concept develops from softer lines to tense and straight stealth inspired lines and surfaces. [Appendix 5]

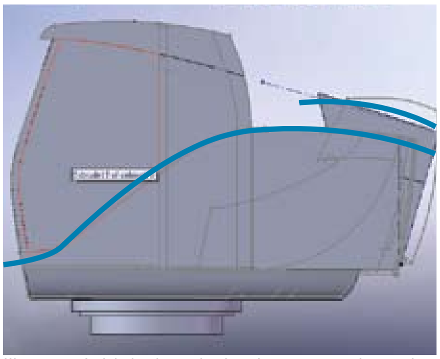
Previous concepts

The illustration 3.7.1 and 3.7.2 shows previous sketches for how the shapes of the undercarriage, tracks and upper carriage are related.

Main concept for the styling

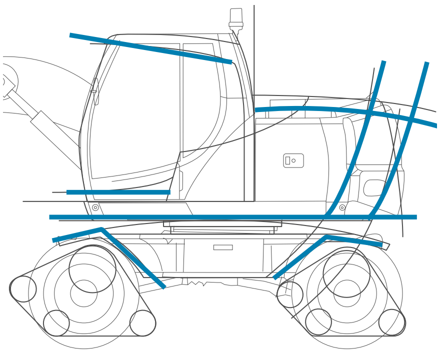
The illustration 3.7.3 shows the main concept for how to create a relation between the counterweight and the excavator. The main lines of the excavator are highlighted.

Related lines



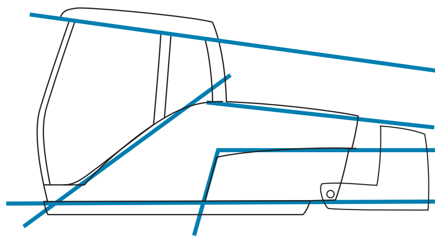
Ill.3.7.1.Initial sketch for how to relate the cw to the excavator.

Guiding lines



Ill.3.7.2. Initial styling concept. Guiding lines are highlighted.

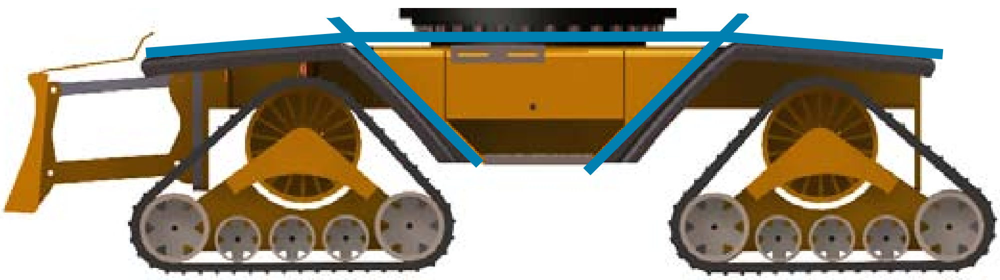
Final ruling lines



Ill.3.7.3.The main lines of the final concept is a stelth like appearience.

Industrial/military undercarriage

The main shape of undercarriage is inspired by conceptual military vehicles to obtain an industrial appearance. (ill. 3.7.4)



Ill. 3.7.4. Undercarriage.

Yellow body

The intention of creating the yellow main body has been to create an overall body and an illusion of a rear end that is lifted because of the darker lower body. Hereby the rear end seems light despite of the dimensions of the excavator. (ill. 3.7.5)

Ill. 3.7.5.Upper carriage

Counterweight dimensions

When the main style of the excavator is determined, it is important to examine the potential of the tip-down counterweight.

Throughout the process, the design group uses simple models to be able to calculate the increase of potential lifting power compared to the offset of the counterweight. By comparing the calculations and counterweight offset with a 3d-model of the excavator, the design group is able to evaluate the functional aspects of the counterweight compared to the preferred expression of the excavator.

Simple static model

The calculations display the force that the bucket can handle with an extended counterweight before the excavator tilts. The system does not take into account deformations or fractures, but only the momentum at the side and front axis.

The excavator is divided into four parts; the bucket, the arm, the upper/undercarriage and the counterweight. The weights of the parts are found using the product brochures and a datasheets provided by Hydrema. The length to the point of gravity of the separate parts is estimated by eye. To consider the working situations of the excavator, 3 different scenarios are created; normal reach, side reach and reach w. dozer lowered (ill. 3.8.2 – 3.8.4).

Tilt estimation model

The first thing listed will be the weight of the individual parts:

$M_{Arm} := 2974kg$ $\quad M_{Body} := 9826kg$

$M_{CW} := 4100kg$ $\quad M_{CW\_old} := 4200kg$

The forces can now be found by multiplying with the gravity acceleration.

$$g = 9.807\frac{m}{s^2}$$

$$F_{Arm} := M_{Arm} \cdot g = 29.165 \cdot kN$$

$$F_{Body} := M_{Body} \cdot g = 96.36 \cdot kN$$

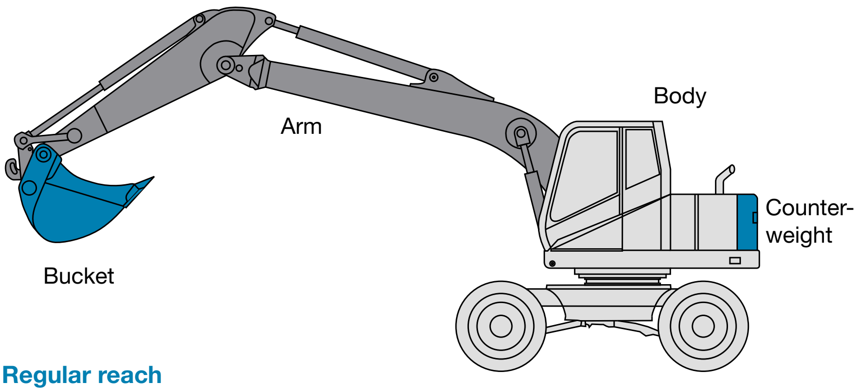
$$F_{CW} := M_{CW} \cdot g = 40.207 \cdot kN$$

$$F_{CW\_old} := M_{CW\_old} \cdot g = 41.188 \cdot kN$$

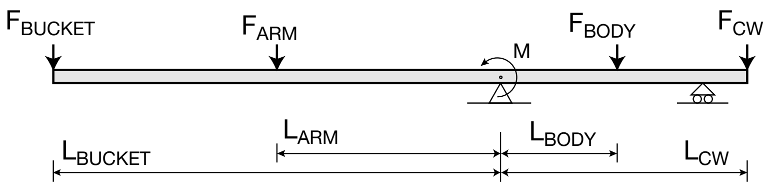
The length relation between the elements is the same in all the systems, so they change the same amount in relation to the point of rotation in the different scenarios. They will be massed on the normal reach length, which is defined as:

$L_{Bucket} := 9.5m$ $\quad L_{Arm} := 4.75m$

$L_{Body} := 1.9m$ $\quad L_{CW} := 3.25m$



Regular reach



The scenarios are a state of equilibrium, where the back wheel is not providing any support, and is left out of the system. The forces on either side of the point of rotation shall be equal, for the excavator to remain in balance, which is translated to:

$$L_{Bucket} \cdot F_{Bucket} + L_{Arm} \cdot F_{Arm} = L_{CW} \cdot F_{CW} + L_{Body} \cdot F_{Body}$$

Regular reach

The force that is used to keep the excavator from tilting is found:

$$F_{Bucket} := \frac{\left(L_{CW} \cdot F_{CW\_old} + L_{Body} \cdot F_{Body}\right) - \left(L_{Arm} \cdot F_{Arm}\right)}{L_{Bucket}} = 18.78 \cdot kN$$

The same equation can now be used to find the value reached when moving the CW further behind. The modifications needed are to add the length moved and the additional force of the body, as the result of the heavier tracks. These are defined as:

$$L_{CW\_move} := 650mm \qquad F_{Track} := 1000kg \cdot g = 9.807 \cdot kN$$

$$F_{Bucket\_CW} := \frac{\left(L_{CW} + L_{CW\_move}\right) \cdot F_{CW} + L_{Body} \cdot \left(F_{Body} + F_{Track}\right) - \left(L_{Arm} \cdot F_{Arm}\right)}{L_{Bucket}} = 23.157 \cdot kN$$

Compared to the existing system, this solution will therefore enable the bucket to carry 23% extra compared to the Hydrema M1700 excavator before tilting.

$$\frac{F_{Bucket\_CW}}{(18.78\ kN)} = 123.307 \cdot \%$$

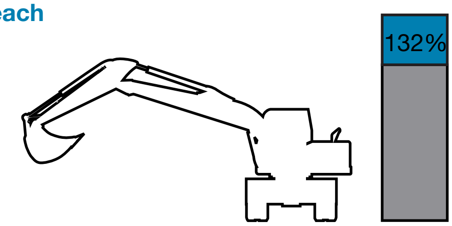
Side / dozer reach

When reaching over the sides or putting down the dozer, the body is moved according to the point of rotation. For a side rotation the body is 35 cm shorter and the boom reach is 35 cm longer, while the dozer relocates the components but 100 cm in the opposite direction. When the corrections according to the lengths have been done, the same calculations as for regular reach can be performed for a side or dozer reach.

Outcome

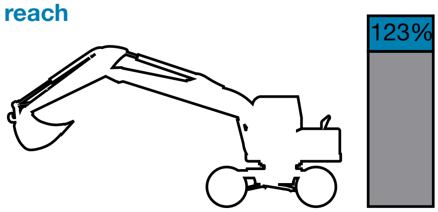
The calculations provide the design group with an overview of the impact that regulations regarding weight and offset of counterweight has on the increase of potential lifting power. Based on the calculations the design group evaluate that an increase in-between 20-25% is enough, since it fulfills the design criteria. To obtain this a counterweight on 4.1 ton may have an offset at 650mm from the excavator in a regular work position.

Side reach



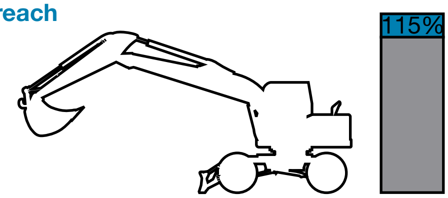
ill. 3.8.2

Regular reach



ill. 3.8.3

Dozer reach



ill. 3.8.4

ill. 3.8.2 - 3.8.4: Simple model describing the increase of potential lifting power compared to M1700C.

Increase of potential lifting power

The increase of lifting power is defined potential lifting power because the increase is only realistic if the hydraulic pumps and the construction of the excavator are built to handle the increase of lifting power.

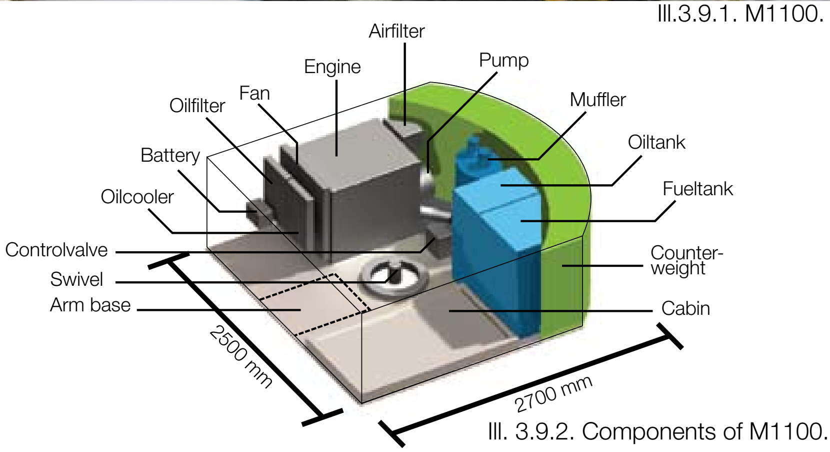
Upper carriage

Considerations on the placement of the counterweight according to the elements of the excavator are explained through the use of reverse engineering.

M1100

Since no technical drawings of the internal structure and components of M1700C are accessible, the design group estimates the elements from the M1100 components/arrangement and the M1700C outer frame measurements from Rhino drawings and CAD drawings from Hydrema. The illustration only represents the approximate size, position and structure of the M1700C. (ill. 3.9.1) Furthermore an extra hydraulic pump is added as is the case in the M1700C, which has two pumps compared to M1100.

Ill.3.9.1. M1100.



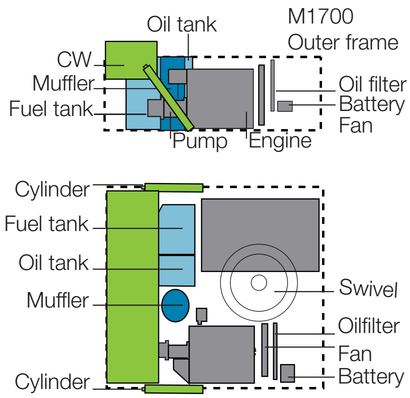
Ill. 3.9.2. Components of M1100.

Components

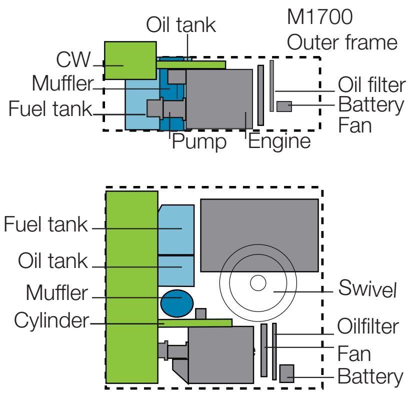
Being aware of the internal elements of the machine provides the design group with an overview of where and how it is possible to place the counterweight and the hydraulic cylinders which activate the motion of the counterweight.

Placement

Different locations are evaluated during the process. The two main examples are illustrated at ill.3.9.3 & 3.9.4. Both suggestions are realistic with minor adjustments to the area concerning the muffler, fuel and oil tank. Also, both suggestions consider the operator by placing the counterweight so it does not block his rear view.



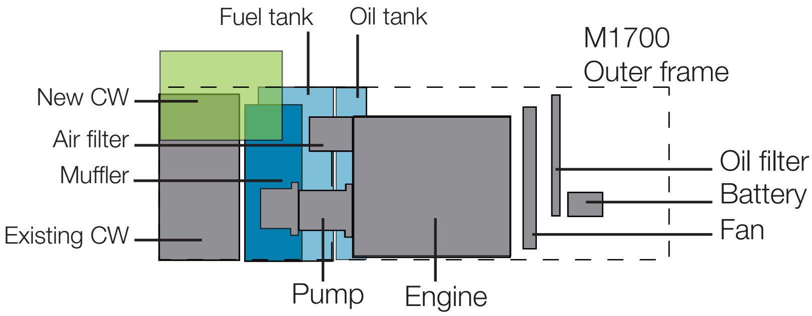
Ill. 3.9.3. Suggestion 1.



Ill.3.9.4. Suggestion 2.

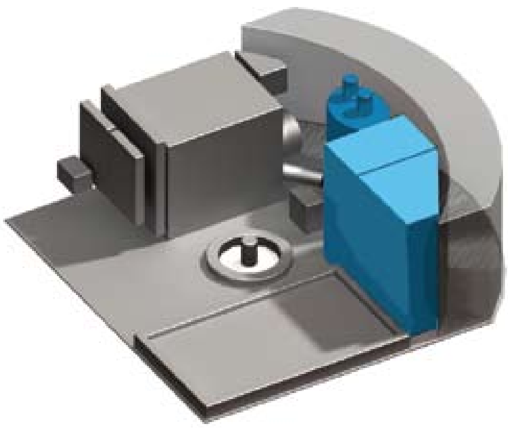
Outcome

The internal elements are to be rearranged in order to make room for the counterweight in the shape. The degree of restructuring is depending on where and how far down in the shape that the counterweight is placed. A weight at 4.1 ton results in the approximate dimensions of 600x400mm based on the dimensions of the flexible counterweight. By an offset of 650mm from the excavator, the counterweight needs to be placed at halfway into the upper carriage at the rear end to avoid blocking the vision of the operator. (ill. 3.9.5)



Ill. 3.9.5. Placement of counterweight in the uppercarriage.

The components that are affected by the placement of the counterweight are the oil-, fuel tank and the muffler. We have therefore reshaped and repositioned the counterweight so we estimate that the elements affected can be reshaped to fit the extra space were the counterweight used to be.



Ill. 3.9.6. Affected components that need to be restructured or reshaped.

As the design criteria states, the functional elements should be used as a part of the expression, so it is chosen to place a cylinder on each side of the excavator. Placing the cylinders on the outside does not conflict directly with other components, but the cylinders still need to be accessible for hoses from the inside. Furthermore an issue is the exhaust, filters and various tank openings near their respective components that have to be accessible for the operator while being placed near respective components.

Ill. 3.9.7. Openings for tanks, oilfilter, exhaust and the airfilter openinghas to be restructured.

Production

The following describes the considerations regarding the production methods of the counterweight.

When choosing between the various concepts, important criteria have been to design a construction that can be produced at the facilities at Hydrema. These considerations are essential when choosing the principle for expanding and shaping the counterweight.

To rely on in-house production of Hydrema is a choice based on conversations during meetings with Hydrema where the approach has had positive feedback. The cost is also considered to make sure that the added machine cost is lower or equal to the gain of the features.

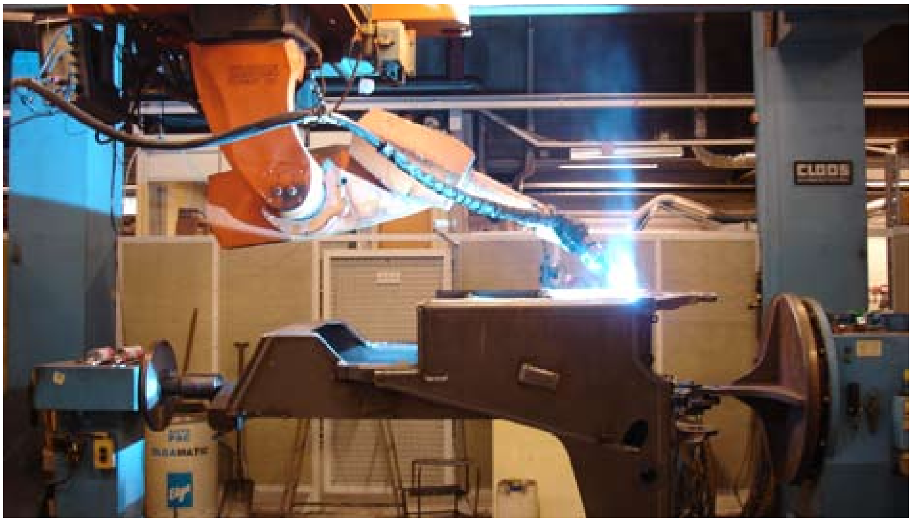
The production methods available at Hydrema in Støvring are:

- Flame cutting (max. 100mm)
- Laser cutting (max. 20mm)
- Bending (standard max. 12mm, special max. 30mm)
- Welding

Furthermore, the construction should be done in the same materials as their subsuppliers are currently selling them. The metal sub supplier of Hydrema is the Swedish metal supplier, Svensk Stål, www.SSAB.dk. Svensk Stål is capable of supplying various kinds of steel with different qualities and thicknesses. The main considerations regard the rough production methods. Assembly procedure and final finish has not been taken into account.

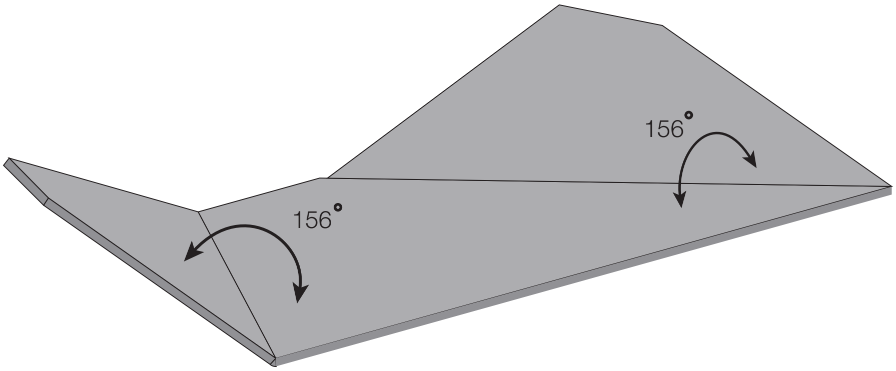
Producing the Counterweight

In order to produce the counterweight various production methods needs to be taken in use. The production of the cylinders is not considered in the project, since Hydrema has standard cylinders that most likely will be used in the construction. It is expected that the main material which is needed for the counterweight is Domex 700 MC, the same material that Hydrema



ill. 3.10.1. The welding machine at Hydrema, Støvring.

ill. 3.10.2. Shovel made of welded metal sheets.

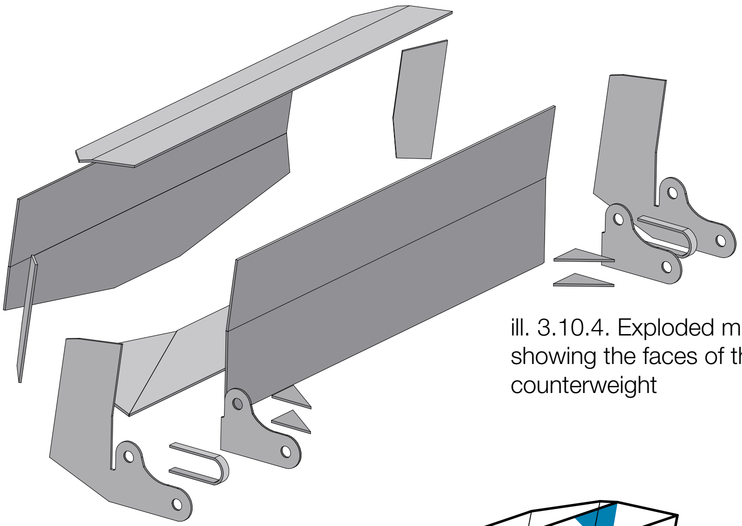


ill. 3.10.3. The bending angles of one of the parts of the counterweight.

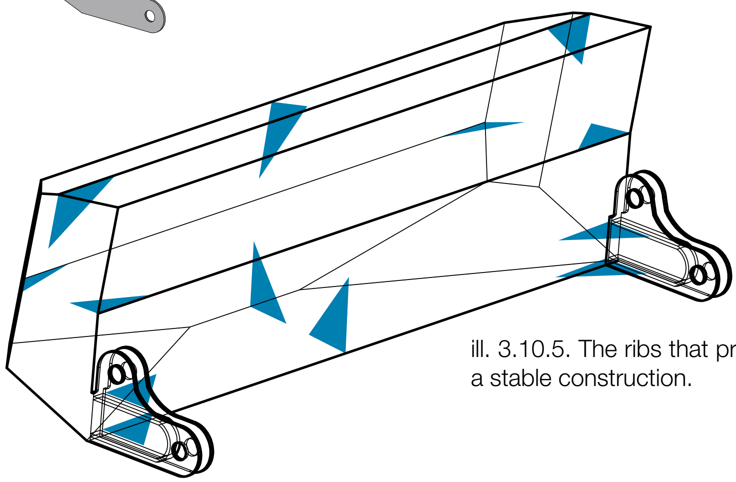
uses for the main construction of the excavator. The step in the process is cutting of sheets into the various counterweight faces. The sheets are 10mm thick, so the procedure is done with laser cutting. When the shapes have been cut, some are bend to fit the final shape. This is done by machine to ensure the correct angles. The elements are then welded together piece by piece. To ensure a stable construction, ribs are inserted as the pieces are joined. (ill. 3.10.5) The welding are placed on the outside of the construction, so that the areas are accessible for welding machines.

Before the top part is welded onto the construction, the ballast is added. To make the production of the counterweight cheaper, the ballast consists of the scrap metal from the workshop, a technique that is already used by other companies such as Hitatchi. (ref. Hydrema).

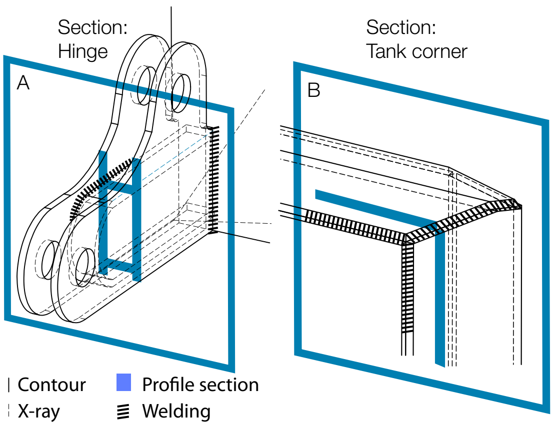
When the counterweight is full, the top part is welded to the shape and the counterweight is mounted on the excavator. This solution is estimated to be cheap compared to the existing solution where the counterweight is casted by a sub-supplier.

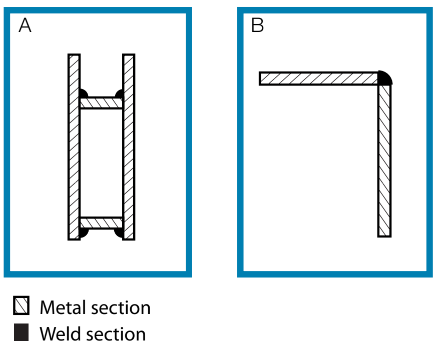


ill. 3.10.4. Exploded model showing the faces of the counterweight



ill. 3.10.5. The ribs that provide a stable construction.





ill. 3.10.6. Section cuts showing the faces and weldings of the hinge.

Under carriage

The chapter describes which modifications are needed to mount tracks on the existing under carriage.

Individual tracks for use on an excavator do not exist neither do tracks intended for a vehicle in a similar weight class. A rough design of the tracks is therefore needed. The design is based on comparing the larger tracks (Tidue, ATI-tracks etc.) for combines and tracks for smaller vehicles (larger cars, trucks etc.). The actual design details are therefore not verified but are sufficient for size approximations and style indications.

The tracks mount in a similar fashion (nuts & bolts) as regular wheels, but there are some differences in size compared to wheels, so the under carriage does need some modifications. Immediate problems are width (interference when turning), height, length and as shown in illustration 3.11.2.

Width

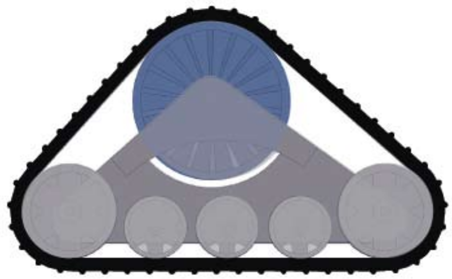
As the tracks are mounted further from the axle, the axle needs to be extended 200-300mm. The excavator turns in the same way as a wheel excavator, so it is preferred to lengthen the axle as to meet the middle point of the tracks, to keep the action radius of the tracks as low as possible. Also it is necessary to design the under carriage to give enough clearance for the tracks to be able to rotate.

Length

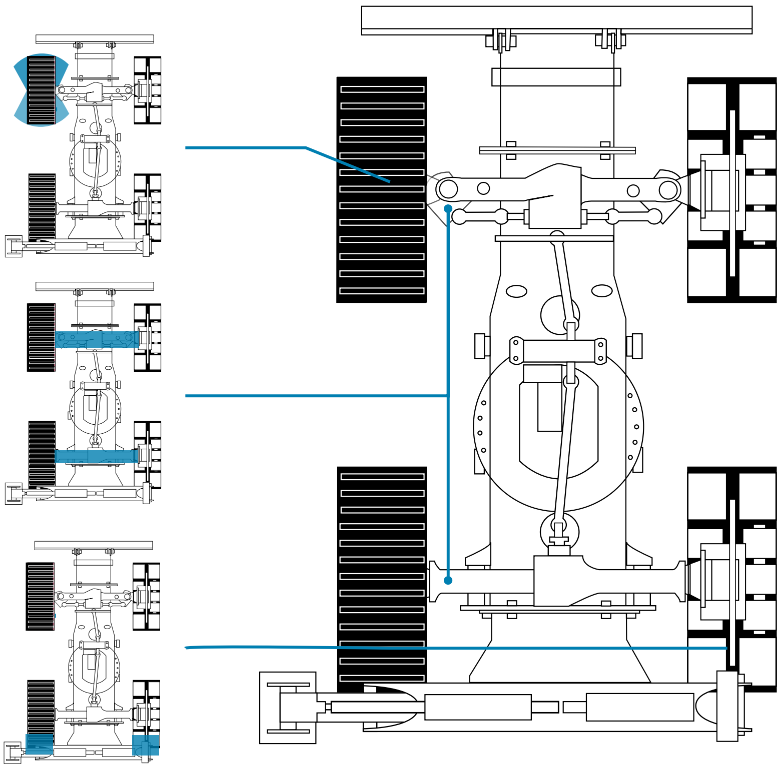
As the tracks are longer than wheels, the axle length decreases, but the distance to the farthest point of support is increased. This gives the excavator a short turning radius as well as better support compared to the wheeled excavator.

Height

The tracks are lower than wheels for the same weight class and feature a different vertical mounting point which means that the axles need to be placed at a higher level on the under carriage to obtain an ideal excavator height. It is possible to create a lower under carriage to obtain a lower center of gravity for the excavator and thereby increasing stability.



ill. 3.11.1 Final design of tracks for the excavator



ill. 3.11.2: Areas of relevance, when mounting the tracks.

Suspension and support

The tracks use the same hydraulically driven axles, steering system and the same drum brake as the existing M1700C.

The tracks are theoretically able to rotate freely around the axle and although it seems unlikely for the tracks to rotate too much, it could become necessary to limit the freedom of this rotation. Limiting this rotation could for example be done through hydraulics similar to the Tidue tracks (ill. 3.11.3).

Being able to lock the position of the tracks could also be a good way of providing stability when the excavator is digging and not moving. This could possibly also eliminate the need for stabilizers. This way the design achieves a stiff frame when working.

ill. 3.11.3: Tracks with a limited rotation, controlled by a hydraulic cylinder.

Dust

When using tracks at high speed (on-road for example) dust and other material from the underlay might whirl into the air. Some kind of shielding should be considered to protect the under carriage/upper carriage from dust, stones etc.

ill. 3.11.4: Mattracks used on a pick up

4th Visit Hydrema

The following describes the 4th visit at Hydrema concerning the product presentation, April the 14th 2008, and the results of phase 3.

At this stage of the process, the main specifications of criterias are stated. Further the solutions are evaluated from the stakeholders POV. This is done to find benefits and uncertainties with the concept that needs to be taken in consideration in the last phase of the project. The concept is presented to Hydrema the on 14th of April. The feedback from Hydrema points out areas, mainly style related, that can be further developed. i.e. the logo. The entire presentation is in appendix 3-c.

Outcome

The presentaition is an opportunity to include the final comments from Hydrema in the concept. The response on the excavator concept is constructive and is considered in the last steps of the project where the final details of the concept is made.

ill. 3.12.1. Renderings from the 4th presentation at Hydrema.

Design criteria #2

Product style

Identification of Hydrema within the styling and graphic

Exposure of functional elements

Overall style with inspiration from stealth. (ill. 3.6.1 & 3.6.2)

Overall dimensions

Weight class 17 Ton

Max. Height 3900 mm

Same width as existing M1700C model from Hydrema Width: 2500 mm

Same length of upper carriage as M1700C model: 2700 mm

Max.Weigth 18 ton

Elements

Same boom as used on the M1700C

Same internal elements as M1700C and placement (-counterweight)

Function

Increase of stability using counterweight and 4 track system.

Placement of counterweigth with min. influence on internal elements

Use existing undercarriage from M1700C with modifications to fit 4-track system and achieve the desired expression.

Function - Counterweight

Increase lifting capacity using a moveable counterweight

Min. 20 % increased lifting capacity when uppercariage is positioned parallel with undercarriage

Min 25 % increased lifting capacity when uppercarriage is positioned perpendicular to the undercarriage

Placement of counterweigth with min. influence on internal elements

Production

Optimization of expenses for counterweigth production

ill. 3.12.2: Design criteria#2

Design criteria #3

The previously stated design criteria #2 are specified further according to production of counterweight, durability of counterweight system and the product style of the excavator. The highlighted criteria in illustration 3.12.2 are the criterias that are further specified in phase 4 and become design criteria #3. (Ill. 3.12.3) This is the final styling details and the functional counterweight system.

Design criteria #3

Product style

Use of Hydrema yellow / Brown

Placement of hydraulics on the each side as a style element as well a functional element

Use Hydrema logo for Hydrema indentification

Use of product logo

Function

Movement of counterweight with hydraulic cylinders

The Eigenfrequency of counterweight when extracted may not interfere with frequence of a hydraulic hammer

Counterweight structure with a decent factor of safety

Production

Use of standard sized hydraulics already produced in-house at Hydrema.

ill. 3.12.3: Design criteria #3


HYDREMA
EX 1700
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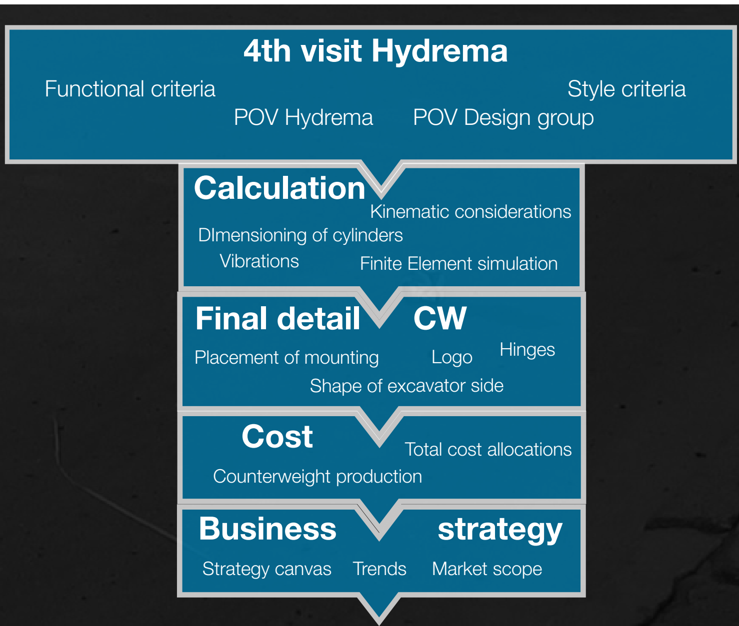
Phase 4: Concept detailing

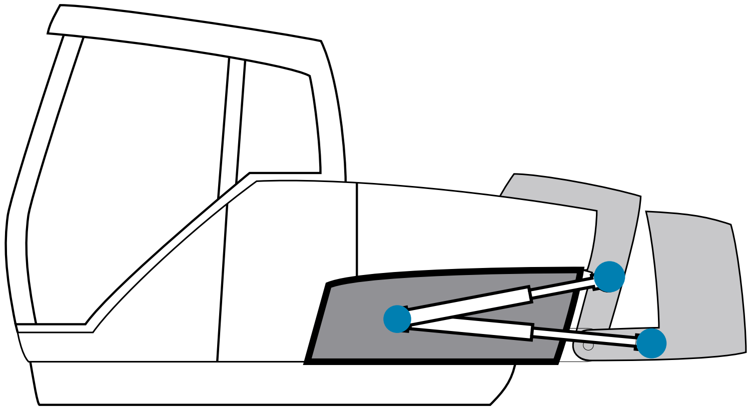


With point of reference in the 4th meeting with Hydrema, the focus is to detail the counterweight system with SolidWorks as a tool. This enables the design group to do several tests on the form and functions to create a final shape suited for manufacturing. Calculations on vibrations from the counterweight are also integrated in the concept detailing supported by the Finite Element Method. Phase 4 is completed by cost allocations and a business strategy to display the project proposal as accountable and market relevant.

Mounting of hydraulics

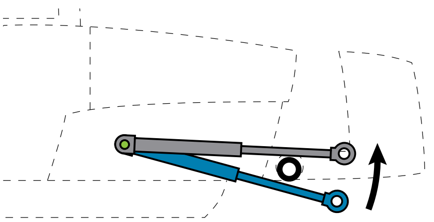
This chapter is a description of the considerations of the placement of the cylinders and the joints that connects them to the excavator and the counterweight.

As stated in the criteria, one of the goals is to implement the functional elements as a part of the styling. The counterweight is essential for the functionality of the concept and it is strived to expose the counterweight and the essential elements for it to function. This means that the hinges and hydraulic cylinders are placed on each side of the excavator and the counterweight to be able to express the function in the design. The lines, the cylinders create and which have to be implement in the overall design are determined by the placement of the hinges. To state the optimal position of the hinges there are some static conditions of the system that must be considered to avoid a cinematic lock condition:



ill.4.1.1. The surface that is disposable for mounting the cylinders on the excavator.

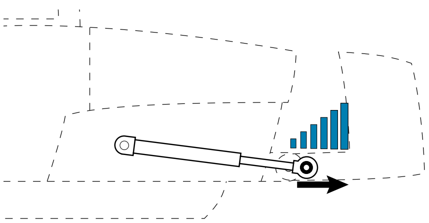
Considerations on how to place the hinges



ill.4.1.4

Actuators

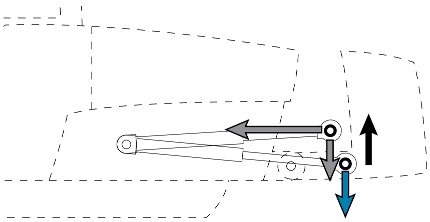
The hydraulic cylinders are used to lower the counterweight around a hinge. To avoid a hydraulic lock it is important that the hinge is not lowered so the piston passes to the same level or other side of the point of rotation.



ill.4.1.5

Horizontal

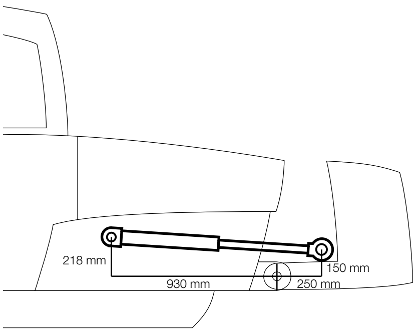
When the cylinder is connected close to the end of the counterweight a smaller amount of power is required to support and raise the counterweight.



ill.4.1.6

Vertical

By raising the counterweight cylinder hinge, less power is needed for pulling the counterweight. The horizontal projected powers of the cylinder are hereby used, when supporting or rotating the arm around the counterweight bottom hinge.



ill.4.1.2. The mounting of the hydraulics.

Outcome

After testing various configurations, the better solution is to place the hinges as shown in illustration 4.1.2.

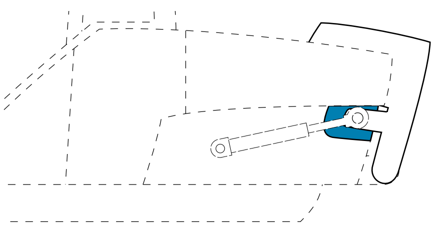
With this solution, the expanded cylinder has an angle of 3.3 degrees and a counterweight arm of 250mm, hereby making it possible to carry the entire counterweight with two cylinders each pulling with a force of 63.7 kN.

ill.4.1.3. The cylinder.

Cylinder dimensions

Hydrema produces 6 different 250 bar cylinders in the range from Ø50/25 to Ø125/63. Based on calculations the counterweight has to have two Ø85/50 cylinders to have the necessary pull force.

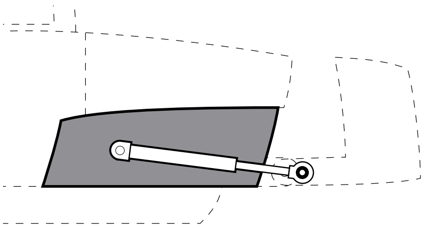
The calculations are only useful in a situation where the cylinders are keeping the counterweight still in the outmost expanded situation. It is expected that the system features either a spring or chain mechanism to support the expanded counterweight. A bigger pull force will be needed when retracting the counterweight.



ill.4.1.7

Hinge lenght

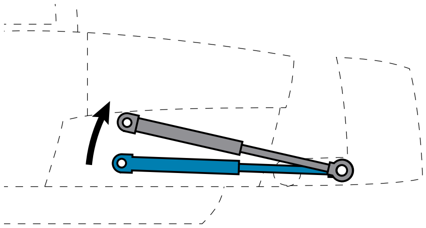
As the counterweight rotates to compact mode, the cylinder hinge length on the counterweight shall still leave room for a cylinder with a size to perform the work necessary.



ill.4.1.8

Variables

The variables that can be changed according to the hinges are according to the position and geometry. The hinge placed on the upper carriage has a limit set by the shapes of the upper carriage, but is preferably placed to create a steep cylinder angle according to the horizontal level.



ill.4.1.9

Target

The target is to obtain a system where the angle of the cylinder is as steep as possible, but also close to the end of the counterweight to achieve a greater arm length. A system that takes these conditions into account has been worked out using a dynamic mathematic worksheet. [Appendix 6]

Vibrations

In this chapter the counterweight system is evaluated according to vibrations, to see how the counterweight eigenfrequency compares to a hydraulic hammer.

When the counterweight is expanded it must be designed so it does not break from the forces of working movements. This could be the forces that occur as a result of rotating the upper carriage, a sudden stop while driving or if the boom hits something, but also the vibrations of the system. These vibrations can be generated by the engine or the use of a hydraulic hammer. The vibrations can be devastating in the frequency of the hydraulic hammer interferes with the eigenfrequency of the counterweight.

Since one of the reasons for the counterweight, is to enable the excavator to work with bigger tools, the hydraulic hammer is used as a test. The eigenfrequencies of the counterweight and the hydraulic hammer are compared to investigate if further absorption of vibrations is needed besides the damping that the hydraulic cylinders provide. For a 20ton excavator a typical hydraulic hammer beats within the range from 350-500 bpm, which is translated to 8.3 Hz.

ill.4.2.1. Hydraulic hammer

Eigenfrequency

When defining the eigenfrequency of the counterweight the spring constants have to be found. These are based on the geometry of the cylinder, the placement of the rod, the amount of force applied from the rod and the bulk modulus of the oil in the cylinder.

$$M_{CW} := \frac{4100\text{kg}}{2} = 2050\,\text{kg}$$

$$F_{cylmod} := 63.691\ \text{kN}$$

$$Bulk_{oil} := 0.7 \cdot 10^9 \frac{\text{N}}{\text{m}^2}$$

$$L_{cyl} := 440\text{mm} \qquad L_{head} := 10\text{mm} \qquad L_{exp} := 395\text{mm}$$

$$\varnothing_{cyl} := 85\text{mm} \qquad \varnothing_{rod} := 50\text{mm}$$

The area of the oil on the pistonhead on the rod and cap side and the lengths of the oil volumes are calculated.

$$A_{cap} := \frac{\pi}{4} \cdot \varnothing_{cyl}^{\,2} = 5674.502 \cdot \text{mm}^2 \qquad A_{rod} := \frac{\pi}{4} \cdot \left(\varnothing_{cyl}^{\,2} - \varnothing_{rod}^{\,2}\right) = 3711.006 \cdot \text{mm}^2$$

$$L_{cap} := L_{exp} = 395 \cdot \text{mm} \qquad L_{rod} := L_{cyl} - L_{exp} - L_{head} = 35 \cdot \text{mm}$$

Afterwards the length that the oil is stretched or compressed is found:

$$P \cdot A = F = \frac{Bulk_{oil} \cdot A}{L} \cdot \Delta L$$

$$\Delta L = \frac{F}{\left(\frac{Bulk_{oil} \cdot A}{L}\right)} = \frac{F}{\left(\frac{Bulk_{oil} \cdot A_1}{L_1}\right) + \left(\frac{Bulk_{oil} \cdot A_2}{L_2}\right)}$$

Knowing the value means that the spring constant of each container can be found. Hooke's law is used and the spring constants are added as serial connected springs, since they placed end to end on both sides of the piston head.

$$\Delta L := \frac{F_{cylmod}}{\left(\frac{Bulk_{oil} \cdot A_{cap}}{L_{cap}}\right) + \left(\frac{Bulk_{oil} \cdot A_{rod}}{L_{rod}}\right)} = 0.756 \cdot \text{mm}$$

$$k_{cyl} := \frac{cylmod}{\Delta L} = 8.428 \times 10^4 \cdot \frac{\text{kN}}{\text{m}}$$

The natural angular velocity is found:

$$\omega_n = \sqrt{\frac{k}{m}} \qquad \omega_n := \sqrt{\frac{k_{cyl}}{M_{CW}}} = 202.757 \cdot \frac{rad}{s}$$

The eigenfrequency is calculated:

$$freq := \frac{\omega_n}{2\pi} = 32.27 \cdot Hz$$

Outcome

The counterweight frequency compared to the hydraulic hammer working frequency is four times higher. It is estimated to be a realistic value for the two systems to be out of each other's range. It should also be noticed that the frequency of the hammer will change, as it is connected to the upper carriage through the boom which, has several pistons that work as dampers to absorb the vibrations.

If the frequencies nearly match, it is possible to do adjustments without affecting the counterweight. The options can be a re-dimensioning of the cylinder, using another kind of oil or add hydraulics/springs.

Damping

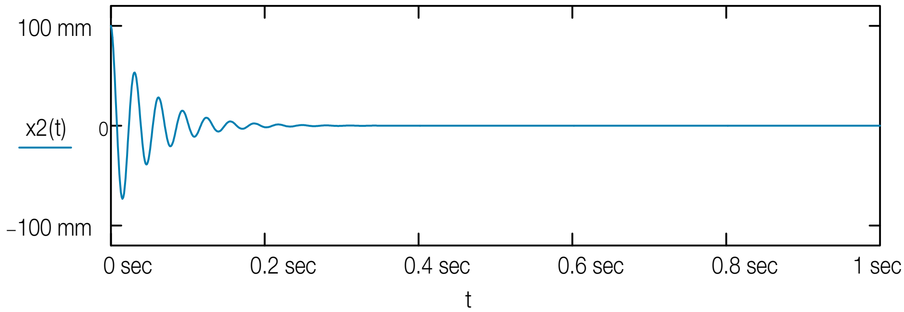
The system also needs to be damped to control the vibrations. The damping will eventually happen over time but in this system a damper is applied. The damper is found by specifying the criteria, the system shall fulfill. In this setup, it is determined that a 100 mm displacement shall be damped within half a second. It is estimated that a displacement like this will occur as a result of driving over a bump. The time criteria are due to that the counterweight has a large influence on the rest of the machine so the vibrations must be neutralized as quickly as possible.

By setting the zeta value to 0.1, it is possible to obtain the wanted damping.

The result is that the damping system must have an actual damping value of 83130 N*s/m and a critical value of 831303 N*s/m. How the specific system is has not been further investigated.

$$\zeta := 0.1 \qquad \phi := 0 \qquad A_3 := 100mm$$

$$x2(t) := A_3 \cdot e^{-\zeta \cdot \omega_n \cdot t} \cdot \cos\left(\sqrt{1-\zeta^2} \cdot \omega_n \cdot t - \phi\right)$$



ill.4.2.2. Damping of a 100mm displacement.

$$\zeta = \frac{c}{2 \cdot \sqrt{k \cdot m}} \qquad c_{act} := \zeta \cdot 2 \cdot \sqrt{k_{cyl} \cdot M_{CW}} = 83130.312 \cdot \frac{N \cdot s}{m}$$

$$\zeta = \frac{c}{c_{cr}} \qquad c_{cr} := 2 \cdot M_{CW} \cdot \omega_n = 831303.124 \cdot \frac{N \cdot s}{m}$$

Hinges

The following paragraph explains the detailing of the hinges hinges that connect the counterweight to the hydraulics.

An essential detail in the system of the counterweight is the hinges. The construction and shape of the hinges are therefore further specified through a Finite Element Analysis in order to obtain an optimal solution regarding the stresses, strain and deformation of the structure. This analysis will provide the necessary information for developing a final concept proposal. Ideas about aesthetics and technical aspects of this system are presented and developed into a final concept proposal.

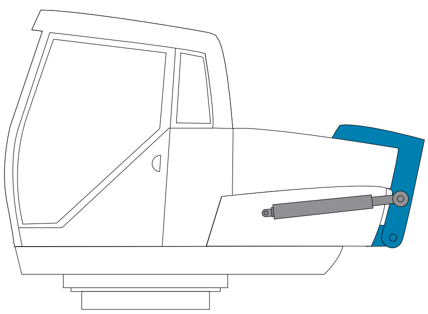
Counterweight

The movement of the counterweight is a rotational movement around the bottom hinge placed on the upper carriage. The movement is driven by the hydraulic cylinders placed on the side of the excavator. This movement outlines some specific demands for the placement of the hinges and their design. (ill. 4.3.3)

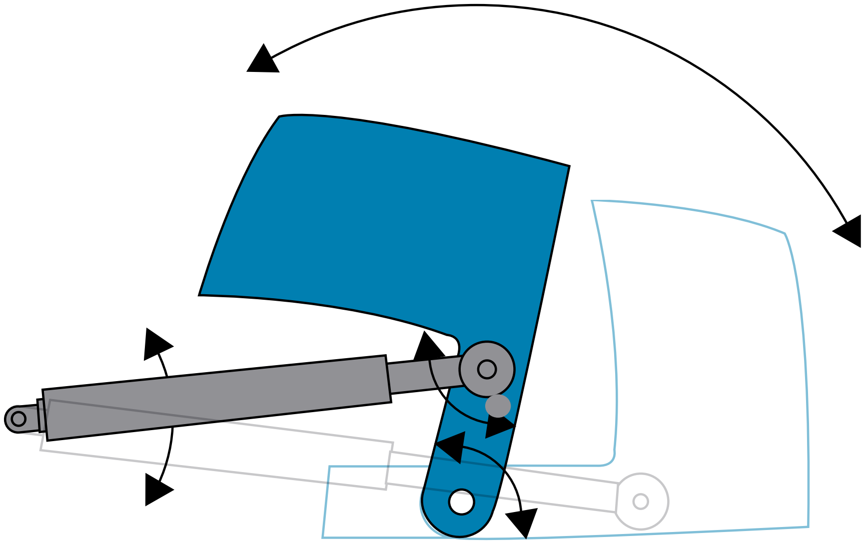
The eye on the hydraulic rod shall rotate around the bolt and the hinge in an angle near 90 degrees, when the counterweight is moving from the retracted position to extracted position. Furthermore, the bolt shall be perpendicular to the hydraulic cylinder and attached to parallel faces so the hydraulic piston does not push or pull in an inclined angle.

In order to transfer the force, provided from the hydraulic cylinder, into a movement of the counterweight it is to prefer that the bolt is placed between two parallel faces so the structure becomes stiff. The same construction is seen on the existing arm on the excavator where the hydraulic pistons are placed between the parallel faces of the arm. (Ill 4.3.2.)

ill.4.3.2. Inspiration is taken from joints between cylinder and boom.



ill.4.3.1. The initial placement and shaping of hinges.



ill.4.3.3. The actions of the counterweight system.

Designing the hinges

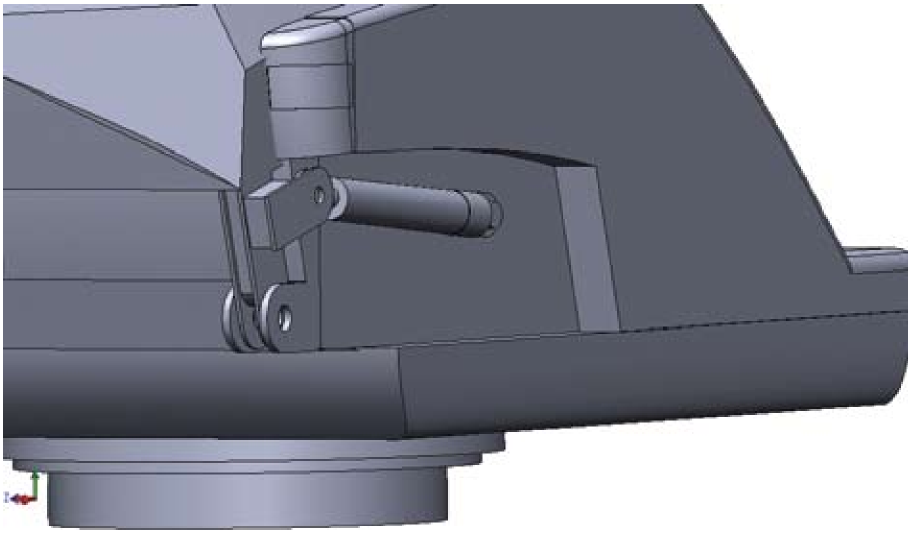
The concept is developed as new issues are raised on the placement of the hinges.

The cylinder is placed in the hollowed area at the backend of the upper carriage. Because of the diameter of the hydraulic cylinder and tolerances when the cylinder is moving the distance between the two cylinders is 2040 mm.

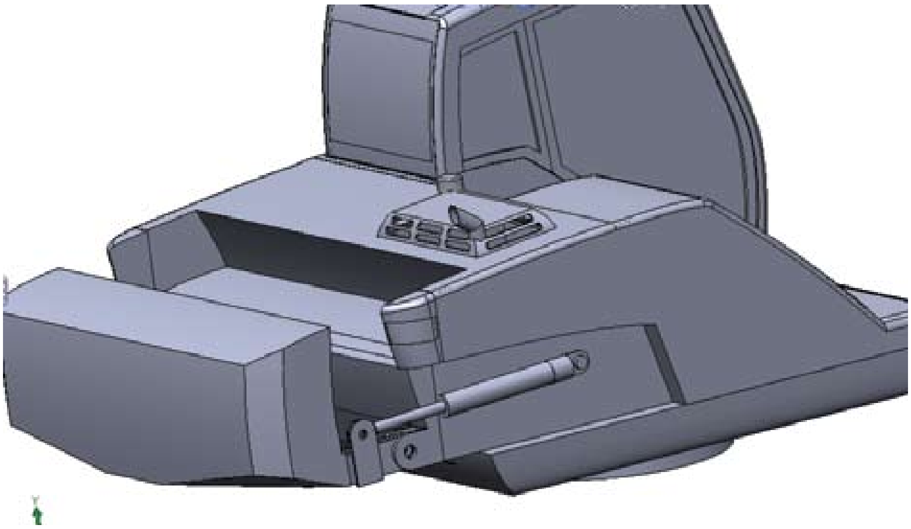
The counterweight is 2024 mm wide, which is based on the aesthetic argument that the counterweight must lie within the upper carriage and deploy from the upper carriage without changing the expression and lines in the upper carriage. (See ill. 4.3.4)

This means that the counterweight must be smaller than the entire width of the excavator and that the remaining surfaces must have some volume in order to fit together with the huge volumes of the remaining design.

The profiles which support the counterweight are placed in the most outer placement possible in order carry the counterweight and reach the hydraulic cylinders which have to pull in the profiles to make the counterweight rotate out to its extracted position. The profiles are straight which increases the simplicity in production. Furthermore the profiles are attached by hinges to the undercarriage (ill. 4.3.5).



ill. 4.3.4

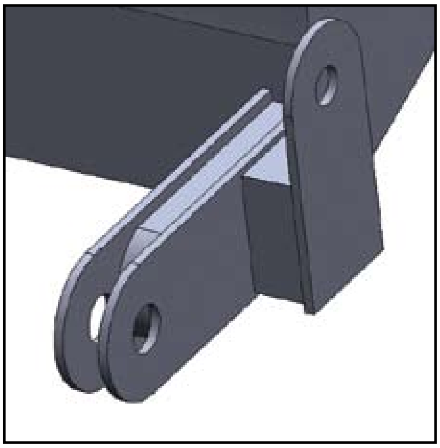


ill. 4.3.5

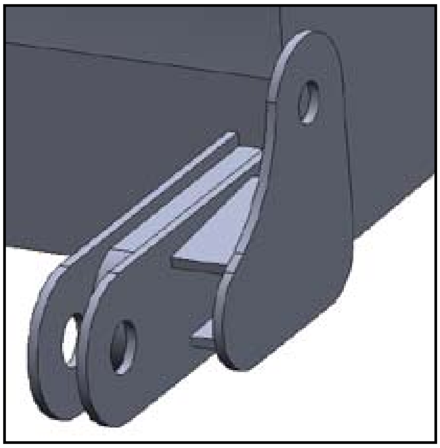
Several design proposals are made in order to create a hinge on the side of the profile which makes the cylinder attached to the profile. The hinge must fulfill the following criteria:

- Must be able to handle the large forces imposed by the hydraulic cylinder
- Must enable the rotation of the hydraulic cylinder
- Must have a face parallel to the cylinder which a bolt can be mounted in

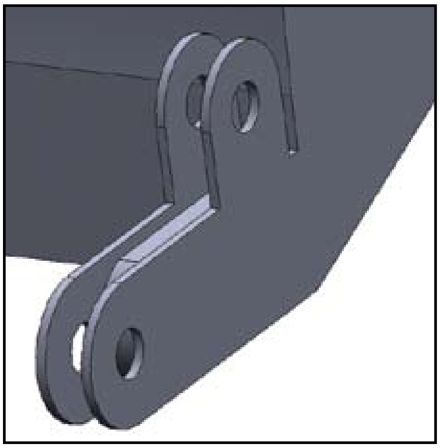
The solutions are tested in CosmosWorks in Solid Works in order to get an impression of the mechanical qualities of the different proposals. (ill. 4.3.6 – 4.3.9)



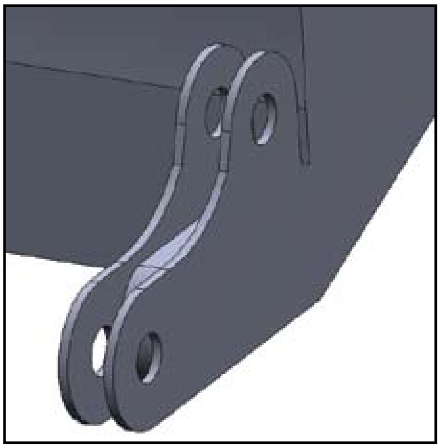
ill. 4.3.6



ill. 4.3.7



ill. 4.3.8



ill. 4.3.9

Finite Element Analysis

The following paragraph continues the detailing of the hinges. Design proposals are tested in CosmosWorks with Finite Element analysis, and a final design for the hinges is chosen.

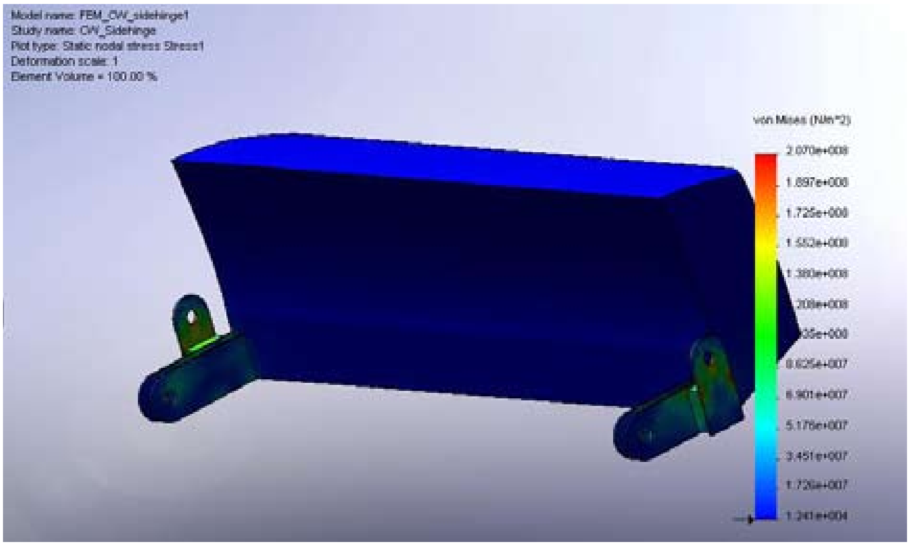
In order to do the Finite Element analysis, the procedure from Mechanics & Numerical Methods is followed, which states the following main points for reporting a Finite Element analysis.

This procedure is used to communicate the steps completed in the Finite Element analysis to the reader. These steps are important in order to give the reader insight to the choices made when setting up the model.

In this case the Finite Element analysis is made in order to compare the different design proposals. The colored plots which can be extracted from CosmosWorks represent stress, displacement and strain in the structure. (ill. 4.4.1) The colored plots will be used to visually evaluate the design proposals against each other. Thereby a basic understanding of deformation and stress concentration in the structure is obtained. The information is then used to sketch a new design proposal, which can be tested again, and thereby obtaining and improvement of the design. The following text will present the first and the last design proposal and briefly sum up the steps between the two design solutions. For the excel sheets used during this process, please see appendix 6.

Finite Element analysis procedure

1. Present a figure of the physical system
2. Make an equivalent figure with model loads
3. If available, explain your hand calculations
4. Show and explain mesh
5. Explain choice of material
6. Showthe deformed figure
7. Present simple results first
8. Show FOS plot and etc.



ill. 4.4.1

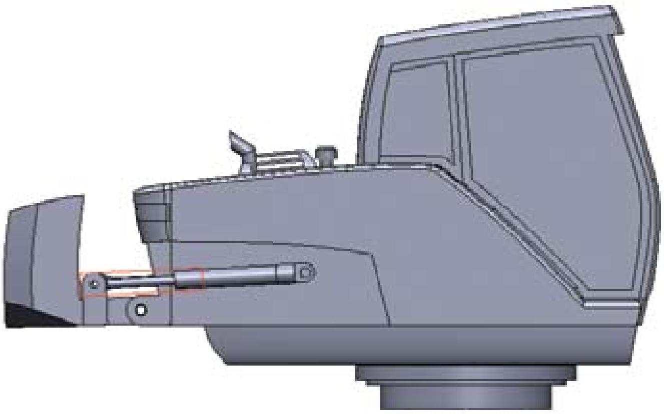
Model 1

Design proposal one is based on the main idea of making a plate where the hydraulic cylinder can be attached. A rectangle of steel walls is made in order to connect the plate with the steel profile that moves the counterweight. The length of the rectangular profile placed between the steel plate and the steel profile for the counterweight is determined by how wide the counterweight is and thereby how far to the sides the steel profiles for the counterweight are placed. (ill. 4.4.2 – 4.4.3)

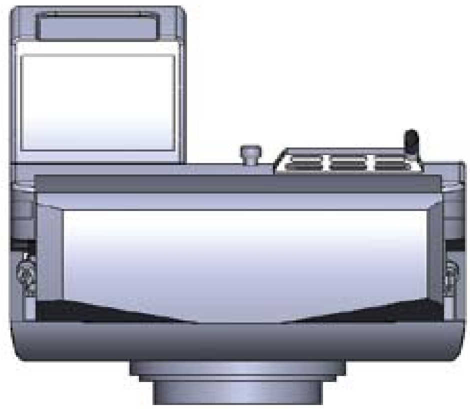
Ill. 4.4.4 shows the simplified model of the structure. The model is used to calculate the forces which affect the system. Afterwards the calculated forces are placed in the computer model in CosmosWorks. Furthermore the model is used to make some basic calculations on stress and displacement in order to validate the results produced in CosmosWorks.

As seen on the simplified model the structure is similar to a cantilever beam with forces like the forces applied by the counterweight and the hydraulic cylinder.

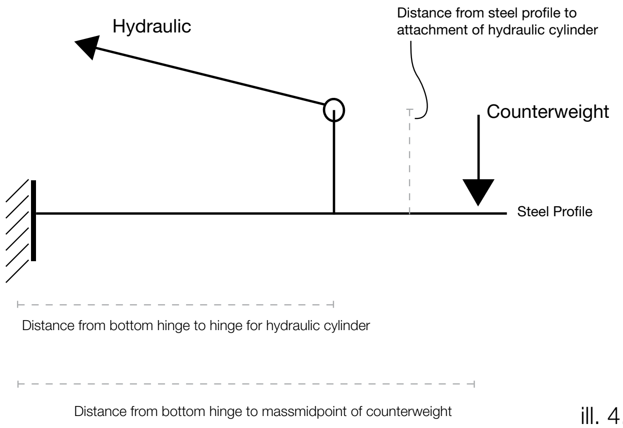
Even though the real structure is attached in a pivot point the model is simplified to a cantilever beam. This is done because the purpose of the test is to see how the hinges between the hydraulic cylinder and the steel profile supporting the counterweight, reacts according to the applied forces.



ill. 4.4.2



ill. 4.4.3



ill. 4.4.4

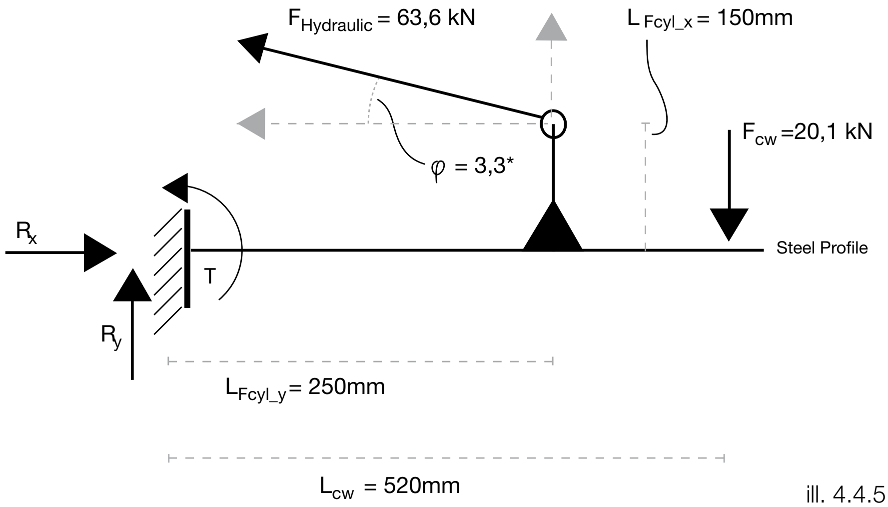
Calculations - model 1

In order to validate the output from CosmosWorks, calculations are made by hand to see if they relate with the calculations from the program.

Calculating expected stress and displacement in the structure.

The setup for the calculation is based on the situation when the counterweight is extracted and the hydraulic cylinder is holding the counterweight in a standstill.

This result is expected because the hydraulic cylinder is pulling with a force equal to the force applied by the counterweight. The system is therefore in equilibrium at the point T. The small difference in the result is due to rounded shapes.



ill. 4.4.5

$F_{cyl} := 63.6kN$ $\quad \phi := 3.3deg$ $\quad F_{cw} := 20.1kN$

With an angle of 3.3 degress

$$F_{cyl\_x} := F_{cyl} \cdot \cos(\phi) = 63.495 \cdot kN$$

$$F_{cyl\_y} := F_{cyl} \cdot \sin(\phi) = 3.661 \cdot kN$$

Sum in X direction

$$R_x := F_{cyl\_x} = 63.495 \cdot kN$$

Sum i Y retning

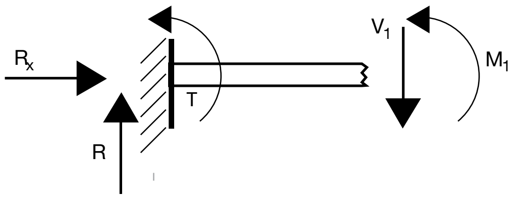
$$R_y := F_{cw} - F_{cyl\_y} = 16.439 \cdot kN$$

After the reactions within the system is found the torque in the point T is calculated

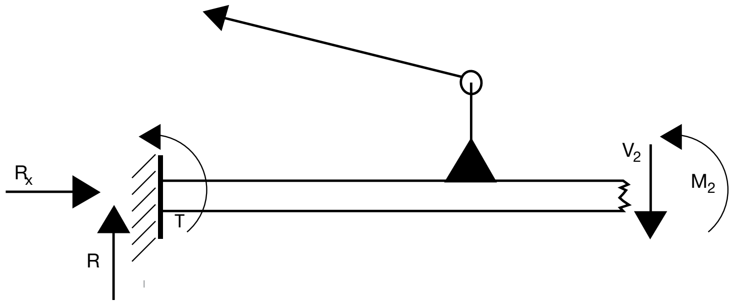
$Lcw := 520mm$ $\quad Lfcyl\_y := 250mm$ $\quad Lfcyl\_x := 150mm$

$$T_{profile} := -L_{cw} \cdot F_{cw} + L_{fcyl\_y} \cdot F_{cyl\_y} + L_{fcyl\_x} \cdot F_{cyl\_x} = -0.013 \cdot kN \cdot m$$

To determine the part of the beam which obtain the highest torque and shear forces the beam is cut into sections. By doing that it is possible to draw a diagram for the shear forces and torque along the beam. Because the force from the hydraulic cylinder is placed between the outer points of the beam two section cuts are needed (one on each side of the force.)



Ill.4.4.6.



Ill.4.4.7.

$0 \leq x \leq 250mm$

Sum in X direction

Sum $F_x := 63.495kN$

Sum in Y direction

Sum Fy = Ry - V1 = 0

$V1 := R_y = 16.439 \cdot kN$

$T_{left\_end} = -V1 \cdot X + M1 = 0$

$M1 := V1 \cdot x$

$250 \leq x \leq 520mm$

Sum in Y direction

Sum Fy = Ry+Fcyl_y-V2=0

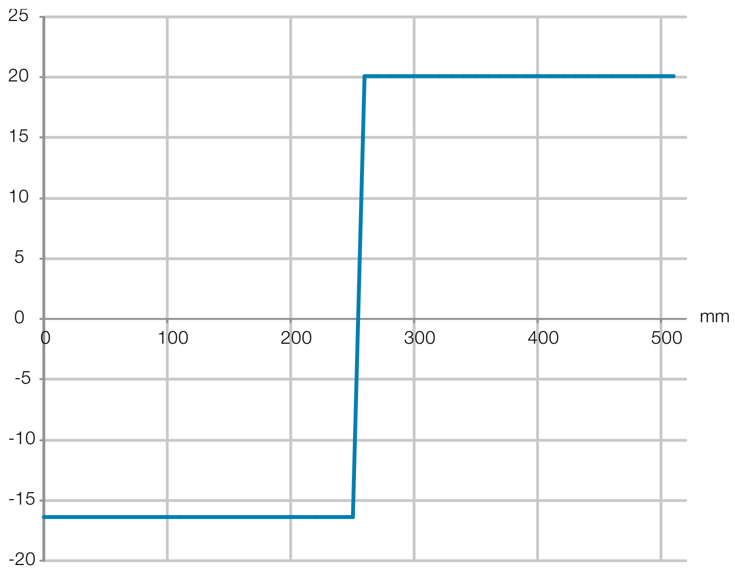
$V2 := R_y + F_{cyl\_y} = 20.1 \cdot kN$

$T_{left\_end} = L_{fcyl\_y} \cdot F_{cyl\_y} + L_{fcyl\_x} \cdot F_{cyl\_x} - V2 \cdot x2 + M2 = 0$

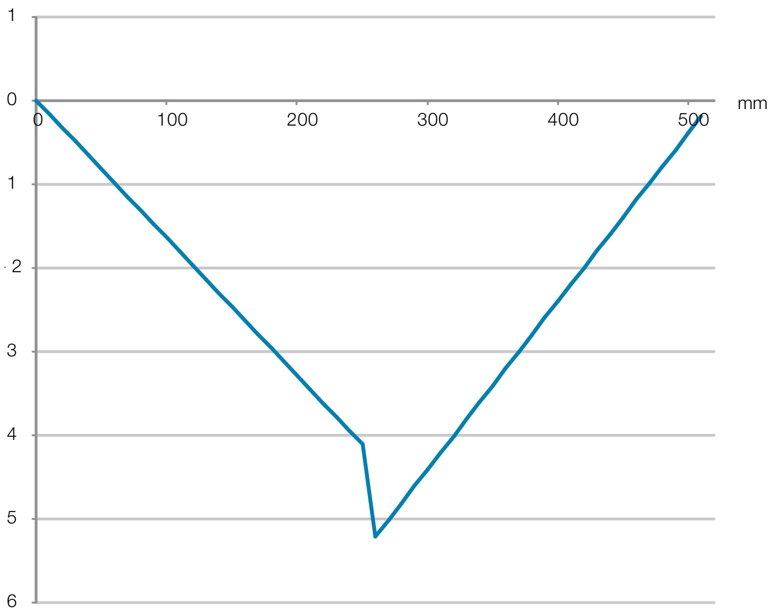
$M2 = V2 \cdot x2 - L_{fcyl\_y} \cdot F_{cyl\_y} - L_{fcyl\_x} \cdot F_{cyl\_x}$

A diagram of the shear forces and torque along the beam is made. The excel sheet which the diagrams are based upon is attached in bppendix 6. As expected the diagram for the torque along the beam indicates that the material is stretched on the upper side while it is compressed on the side turning downwards. The drastic increase in the curve which occurs at x=250 mm is the effect of the small arm holding the hydraulic cylinder.

From the chart it is possible to calculate the maximum stress in the beam and afterwards calculate the deflection of the beam along the axis x.



Ill.4.4.8. Shear force.



Ill. 4.4.9 Momentumcurve.

$$A_{profile} = (WIDTH \cdot HEIGHT) - (width \cdot height) = 3.1 \times 10^3\,mm^2$$

Moment of inertia for the profile. The moment of inertia for the inner rectangle is subtracted from the outer rectangle in order to have the moment of inertia for the square profile.

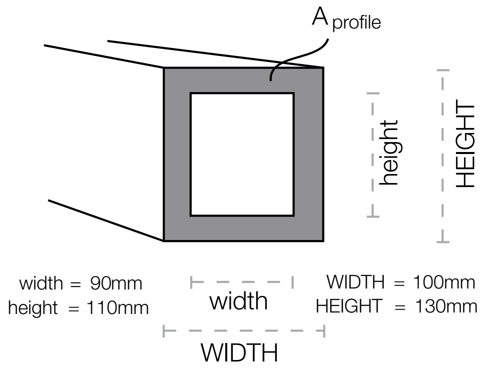
$$I_{profile} = \frac{(WIDTH \cdot HEIGHT^3)}{12} - \frac{width \cdot height^3}{12} = 8.326 \times 10^6\ mm^4$$

The distance from the centerline to the edges of the profile:

$$y = \frac{WIDTH}{2} = 50\ mm$$

Inertia of resistance:

$$W_{profil} = \frac{I_{profile}}{y} = 1.665 \times 10^5\ mm^3$$



Ill. 4.4.10 Dimensions of the A-profile.

$$\sigma_{normal\_axial} = \frac{R_y}{A_{profile}} = 5.303\,MPa$$

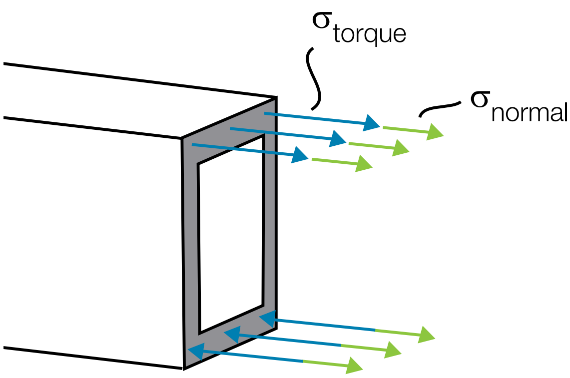
The maximum torque in the beam is found at x = 250 mm

$$T_{max} = 5.414\,kN\ m$$

$$\sigma_{torque} = \frac{T_{max}}{W_{profil}} = 32.516\ MPa$$

Because the σ_{torque} and σ_{normal} affects the beam in the same axis they can be combined in order to find the maximum stress in the beam

$$\sigma_{max} = \sigma_{torque} + \sigma_{normal} = 37.819\,MPa$$



Ill. 4.4.11 Torque.

The maximum shear force in the beam is found at x = 250 mm

$$V_{max} = 20.1\,kN$$

$$\tau = \frac{3 \cdot V_{max}}{2 \cdot A_{profile}} = 9.726\,MPa$$

Deflection of the beam

In order to calculate the overall deflection of the beam each applied force can be calculated from elementary cases, and then added to obtain the combined deflection.

Case 1

The torque in M_0

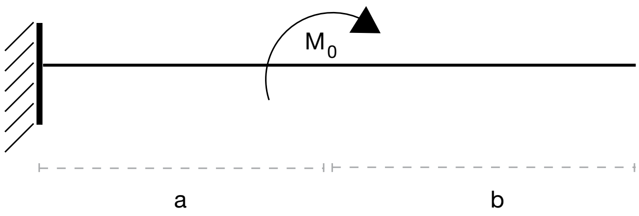
$$M_0 = -F_{cyl\_x} \cdot L_{fcyl\_x} = -9.524\,kN\,m$$

The E-module for Domex 700 steel

$$E = 210MPa$$

$$\nu_{1\_beam1} = \frac{-\left(M_0 \cdot x^2\right)}{2E \cdot I_{profile}} \qquad 0 \le x \le 250mm$$

$$\nu_{2\_beam1} = \frac{-\left(M_0 \cdot L_{fcyl\_y}\right)}{2 \cdot E \cdot I_{profile}} \cdot \left(2 \cdot x - L_{fcyl\_y}\right) \qquad 250mm \le x \le 520mm$$



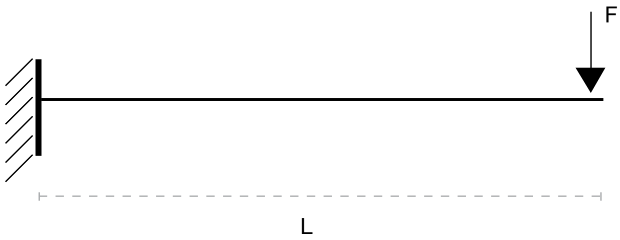
$$\nu = \frac{-M_0 \cdot x^2}{2EI} \qquad 0 \le x \le a$$

$$\nu = \frac{-M_0 \cdot a}{2EI} \cdot (2x - a) \qquad a \le x \le L$$

Ill. 4.4.12 FBD of elementary case 1.

Case 2

$$\nu_{beam2} = \frac{-\left(F_{cw} \cdot x^2\right)}{6 \cdot E \cdot I_{profile}} \cdot \left(3 \cdot L_{cw} - x\right)$$

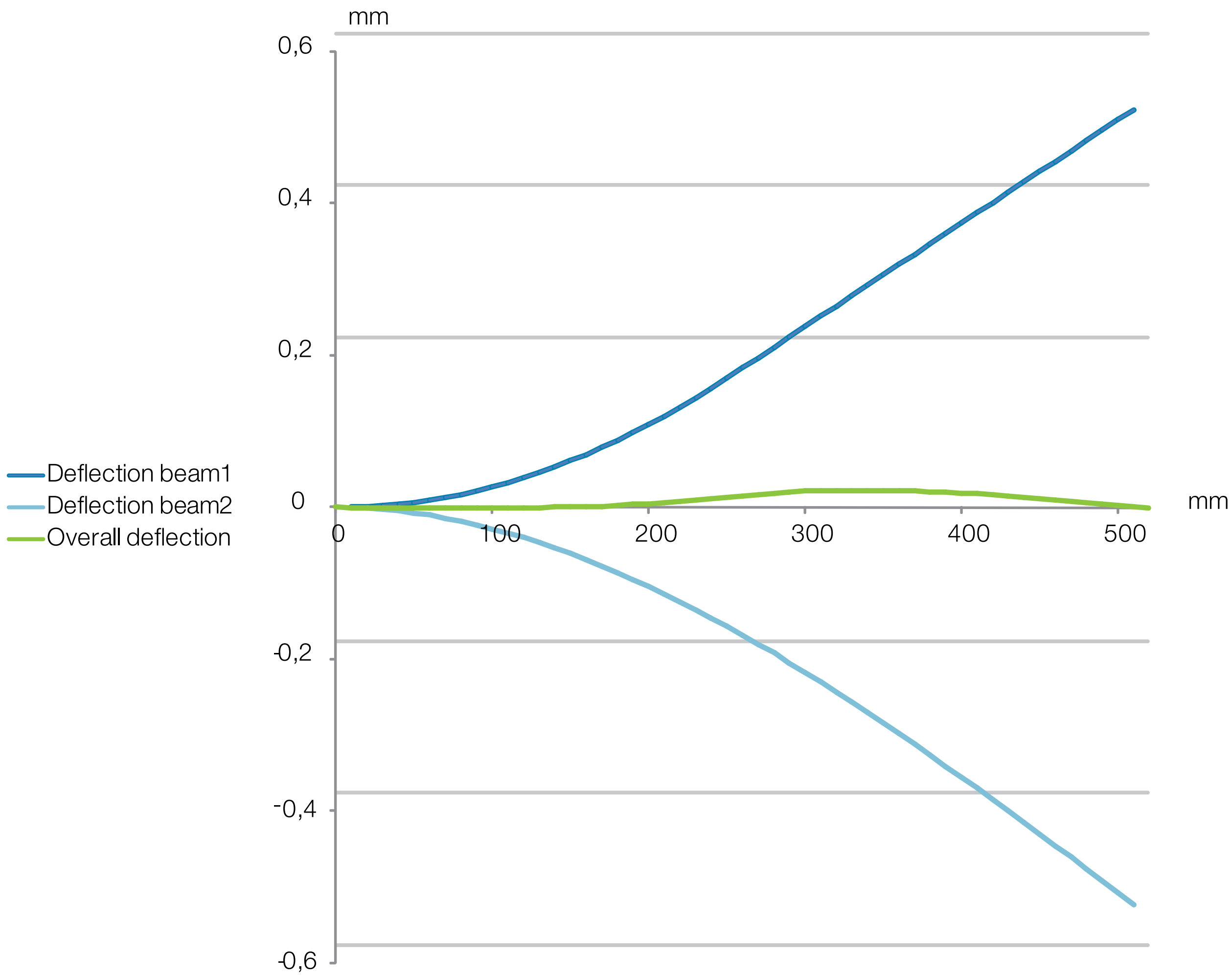


$$\nu_{beam2} = \frac{-\left(Px^2\right)}{6EI} \cdot \left(3L - x\right)$$

Ill. 4.4.13 FBD of elementary case2.

The chart displays the deflection of the beam along the x axis. Both elementary case 1 and elementary case 2 is shown in the chart. They are added together in order to get the overall deflection of the beam which is also shown on the chart. The beam has the highest deflection around the place where the hydraulic cylinder is placed as expected as it pulls the profile upwards while the mass of the counterweight pushes the steel profile downwards.

The diagram is made in excel and can be seen in Appendix 6. The maximum deflection in the beam is 22.5 mm at a distance of 340 mm from the bottom hinge. The deflection is estimated to be acceptable for the design.



Ill. 4.4.14 Chart of deflections.

Setting up Cosmos Works

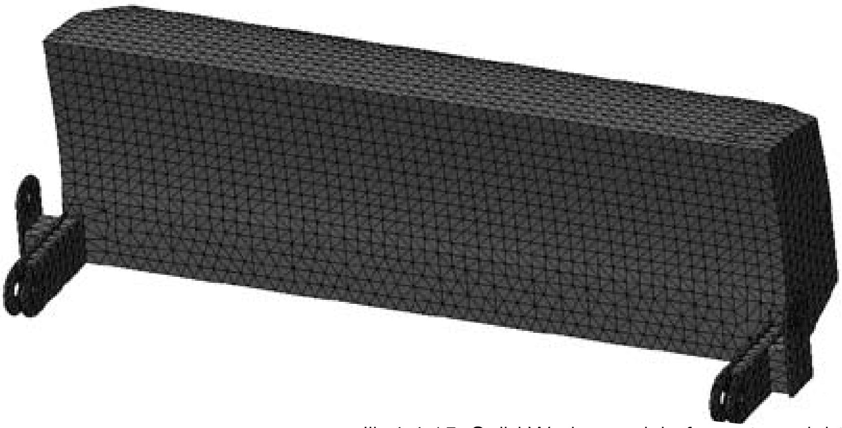
In order to get appropriate results from CosmosWorks it is important to make the right settings in the CosmosWorks model.

First the virtual model is inserted from SolidWorks into the Cosmos Works plug in. Then a mesh is created which transforms the virtual model into a mathematical model which the program uses for simulation. The refinement of the mesh is important for the final results. The more polygons the mesh consists of the more precise is the final result.

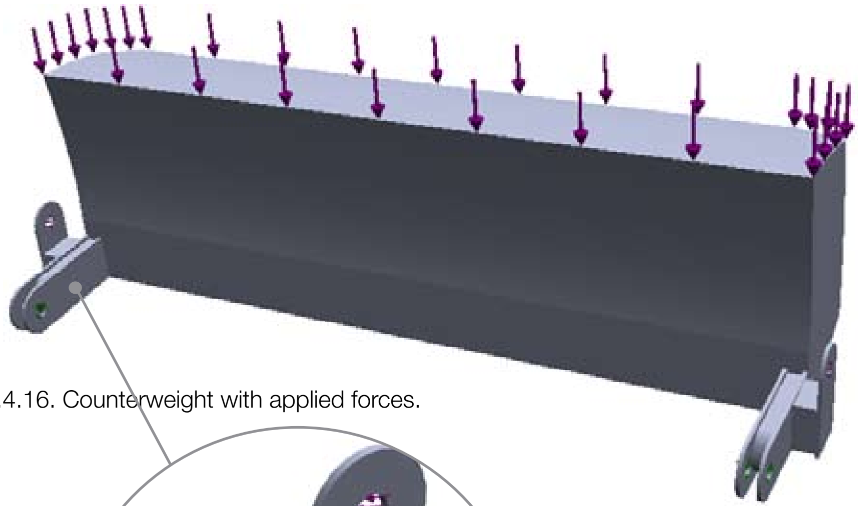
As seen on ill. 4.4.15 the mesh is quite fine and well distributed over the model.

Afterwards material and the specific material properties are added to the model. The material used for the test is Domex 700 MC steel [SSAB 2008].

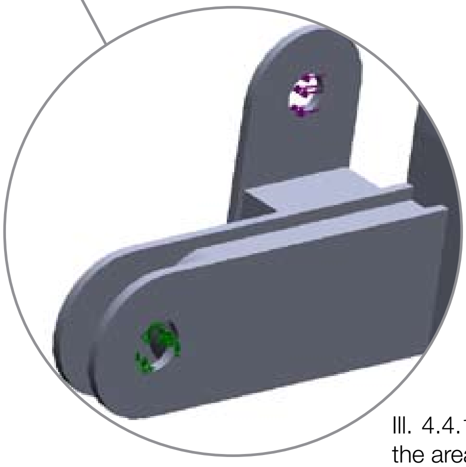
After defining the properties of the materials the forces are applied to the model. In this case the simulation is done according to the scenario where the hydraulic cylinders holding the weight from the counterweight when it is extracted from the excavator. From the calculations it is seen that the hydraulic cylinder must pull with 63.6 kN in order to hold the counterweight. In this case the system is in equilibrium and the system is in a standstill. A force pointing downward corresponding to the weight of the counterweight is placed on the upper side of the counterweight. In the hinges were the cylinder is attached a force is applied on the faces in the cylinder as shown on ill. 4.4.16. Fixed Restraints are placed in the lower hinges to fix the system. (Ill. 4.4.17).



Ill. 4.4.15. Solid Works model of counterweight.



Ill. 4.4.16. Counterweight with applied forces.



Ill. 4.4.17. Hinge with applied forces in the areas where the hinge is fixt.

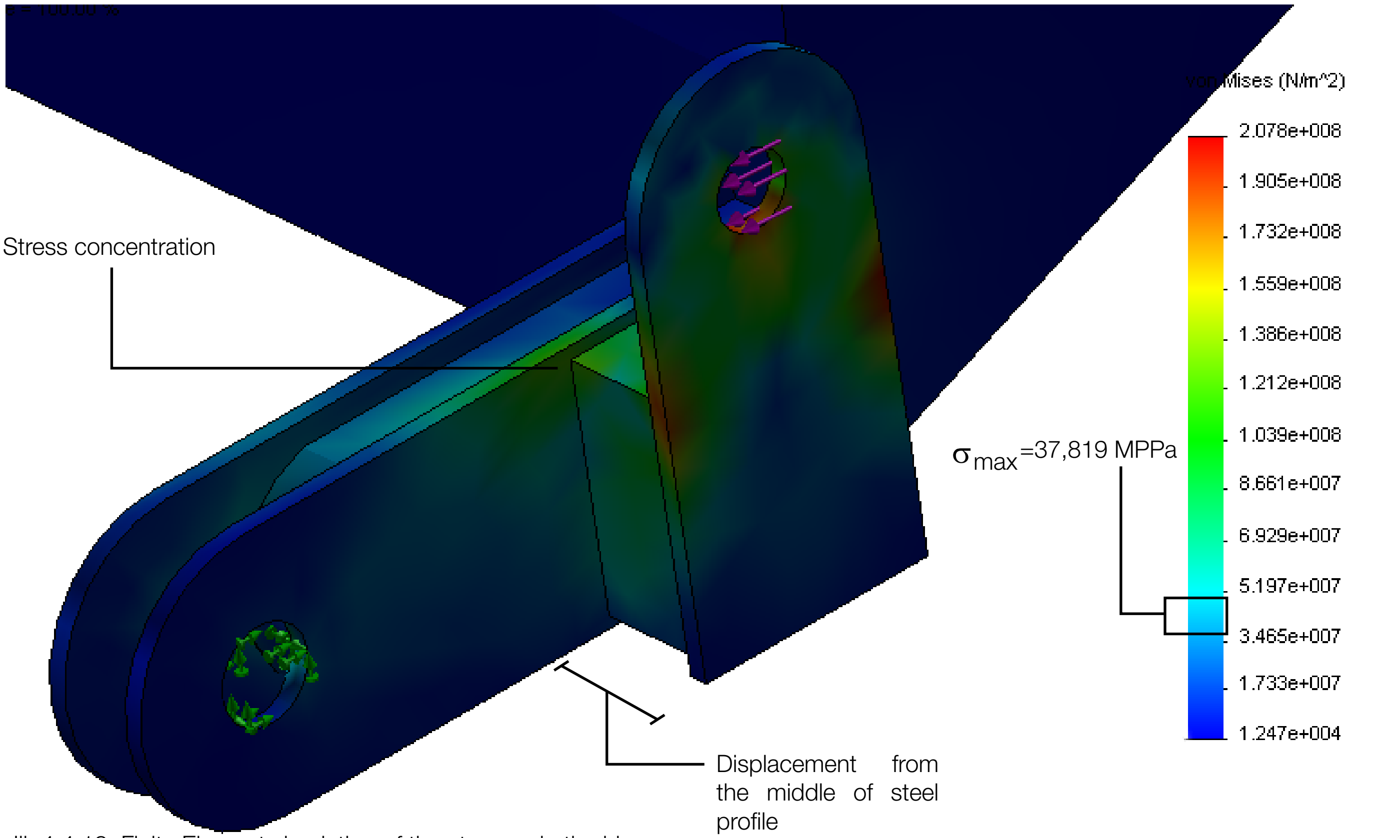
Evaluation of results

In order to evaluate the results produced by CosmosWorks the results are compared with the hand calculations made for the system. On illustration 4.4.18 the stress plot is seen for design proposal one. As seen on the colored bar in the side the structure is stressed from 1,247*10^4 Pa in the dark blue area to 2,078*10^8 Pa in the red area. From the calculations it is estimated that the maximum stress in the beam is 3,272*10^7 Pa when the counterweight is deployed.

Even though the CosmosWorks model is more complex then the model used for hand calculations the results are fairly consistent. The mark on the color bar, which is found by the hand calculations, indicates the expected stress in the beam at the place where the arm for the hinge in mounted. A stress concentration is seen where the hinge is attached to the steel profile. This stress concentration is higher than the expected stress but shows because the hinge is attached on the side of the profile and not in the middle of the profile which the simplified hand calculations assumes.

Stress - Von Mises

Deformation scale 1



Ill. 4.4.18: Finite Element simulation of the stresses in the hinge.

Design Proposal 1

Illustrations 4.4.19 – 4.4.21 shows the results for the CosmosWorks Finite Element analysis for design proposal one. The pictures shows the color plot for stress, displacement, strain and a design check profile showing the factor of safety (FOS) in the model. The factor of safety is measured against the yield strength of the material. Only pictures of the hinges and the profile supporting the counterweight is shown because the evaluation considers the different design proposals for the hinges and the profile.

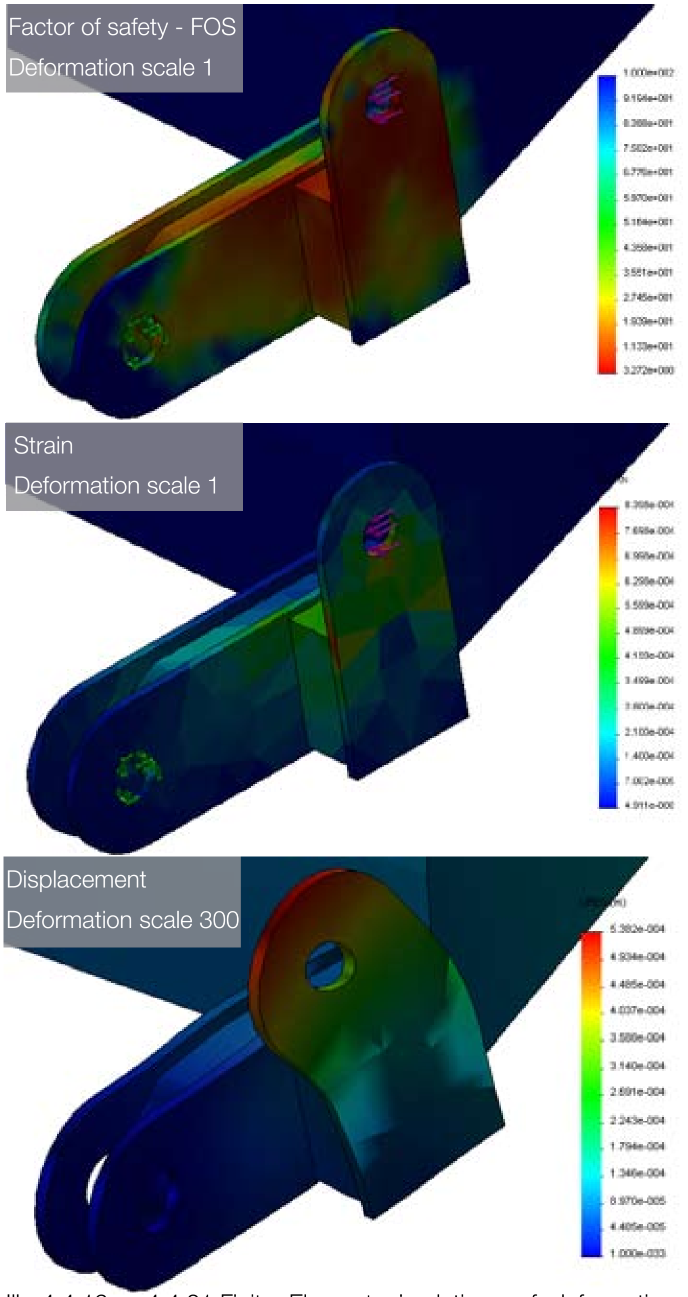
Evaluation of design proposal 1

As seen on ill. 4.4.20 there is some stress concentrations in the structure which is not preferable. As seen from ill. 4.4.21 with a deformation scale of 300 it is seen that the hydraulic cylinder pulls the whole construction sideways and making and uneven stress and deformation in the structure because the hydraulic cylinder is attached to the plate which is fastened on the side of the profile. A more even deformation of the steel profile would have occurred placing the plate in the middle of the profile.

Seen from the FOS plot the minimum FOS is about 3 in the red area and up until 100 in the dark blue area. A big part of the construction is in the red area and it is estimated that 3 is too low a factor of safety for such a construction.

Factor of safety

In order to settle the factor of safety it is estimated how much damage, both material and personal damage, a failure in the construction will result in. It is estimated that if the construction fails somewhere and the counterweight breaks loose from the excavator it can lead to severe personal damage if the excavator tips over due to missing stability. Furthermore the counterweight if the breaks loose it will hit the undercarriage and probably make severe damage on the undercarriage and the tracks. Therefore it is estimated that the FOS should be higher for the tested structure.



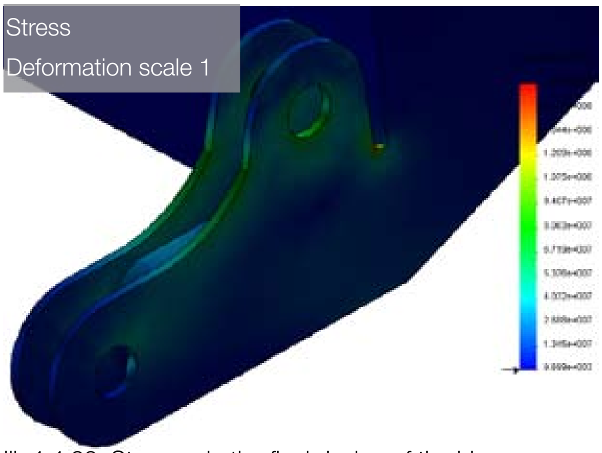
Ill. 4.4.19 - 4.4.21:Finite Element simulations of deformations regarding FOS, strain and displacement.

Final design

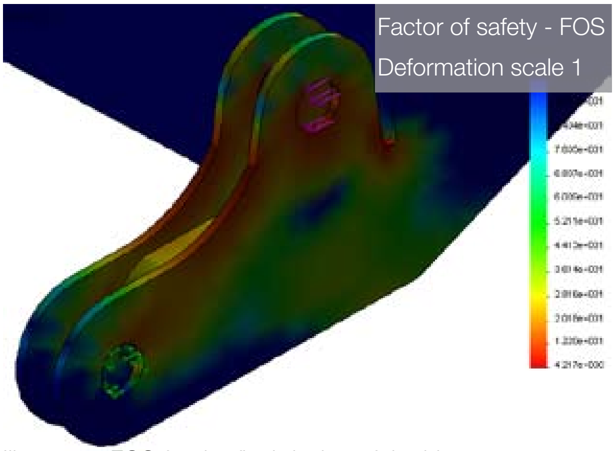
Illustrations 4.4.22 – 4.4.25 show the final design for the hinges and profile supporting the counterweight. The hydraulic cylinder is now attached between two plates which can distribute the force applied to the strong steel profile. As seen on the stress plot the stress in the structure is lower compared to model 1. Furthermore the stress is nicely distributed along the plates. This also has a large effect on the deformation which is seen on the plot for displacement. The deformation scale is 300 like model 1 but the displacement is much lower than model 1. Furthermore the displacement is symmetrical along the beam. The FOS is increased to a minimum of 4,2 which make the construction acceptable according to the settled FOS.

Outcome

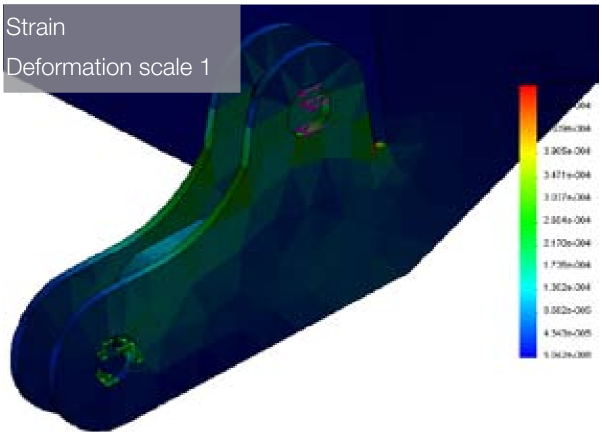
The final design of the hinges has many structural and static advantages compared to model 1. It is easier to produce and it does not consist of as many weldings as model 1. Still the design has drawbacks because it requires that the hydraulic cylinder is placed closer to the middle of the excavator in order to be attached between the plates on the profile. Further work will deal with designing the upper carriage to fit the new solution.



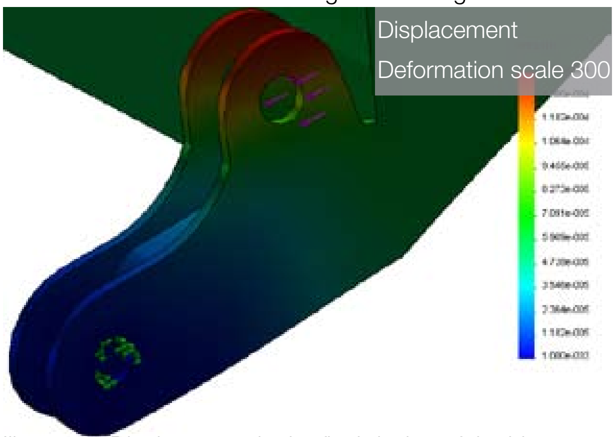
Ill. 4.4.22: Stresses in the final design of the hinge.



Ill. 4.4.23: FOS for the final design of the hinge.



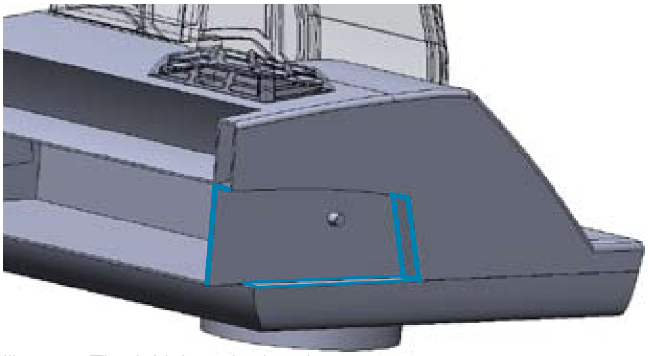
Ill. 4.4.24: Strain in the final design of the hinge.



Ill. 4.4.25: Displacement in the final design of the hinge.

Final design

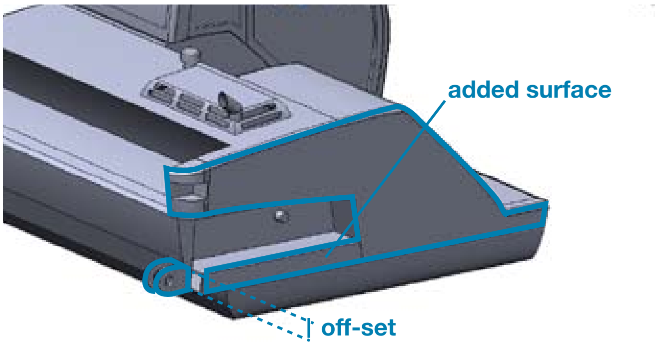
The following concerns the final shaping of the sides of the excavator where the hydraulic cylinders are mounted.



ill.4.5.1. The initial cut in the shape.

Reshaping

The concept proposal presented at Hydrema has a characteristic 100mm deep cut in each side allowing the hydraulic cylinders to reach the counterweight. The Finite Element analysis results in a reshape of the hinges which also affect the cuts on the sides of the excavator. For the cylinders to be placed inside the hinge, the cuts in the sides have to be 100mm deeper than expected. Also there needs to be space for the solid of the hinge that is mounted in the bottom of the upper carriage. Several proposals are modeled in SolidWorks where the criteria are to expose the functional elements and obtain a sharp and edge cut referring to the stealth style.(ill. 4.5.1)

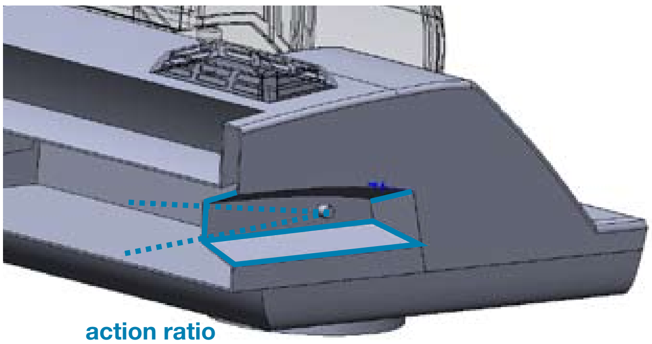


ill.4.5.2. The offset caused by the hinge.

Mount of bottom hinge

To ensure a stable mount of the hinge on the undercarriage the hinge is mounted on the bottom frame of the upper carriage. This affects the height of the cut which means that the cut has to have an offset from the bottom frame.

Furthermore the cut is 200mm which appears like a massive cut in the shape. Another concern is how the yellow ”body” will appear when applying an extra surface in terms of the off-set. (ill. 4.5.2)



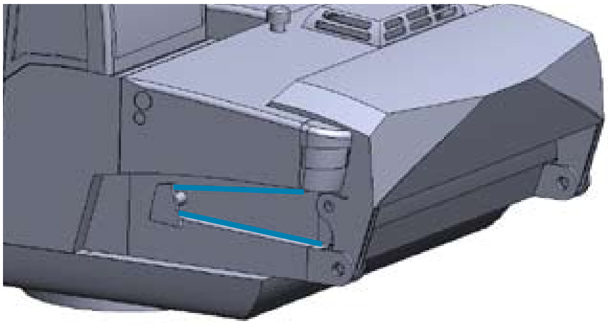
ill.4.5.3. Small action ratio caused by angled surfaces.

Angled cuts

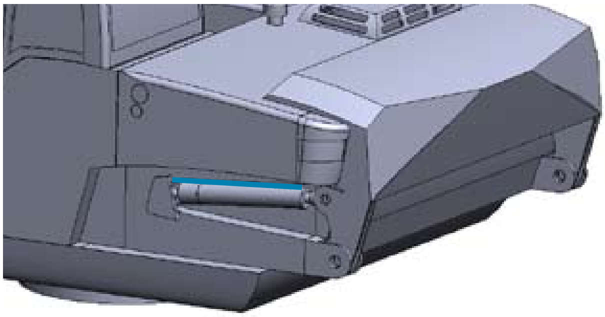
In order to make the cut seem less massive, but still maintaining the sharp edges, angled surfaces are applied. Depending on the angle it may cause problems regarding the action ratio of the hydraulic cylinders because the inner surface is decreased in size. (ill. 4.5.3)

The final solution

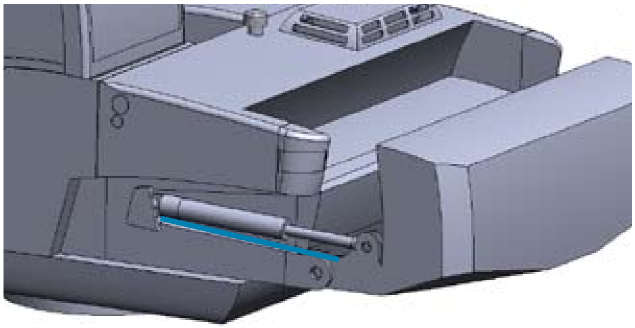
The final shape of the cut on the sides of the excavator is illustrated in 4.5.4 – 4.5.6. The extra 100mm is cut out only where the hydraulic cylinder has a work area. Hereby the cylinders are placed deep into the shape to be able to reach the counterweight. The sharp lines in the cut are maintained and reveal the functional elements. Hereby the criteria of revealing the functional elements and providing a sharp stealth design style to the product is considered not only as an overall style but also regarding specific details of the excavator.



ill.4.5.4. The final shape of the cut out.



ill.4.5.5. In compact mode the top line of the cut is parallel to the hydraulic cylinder.



Ill.4.5.6. In expanded mode the cylinder is parallel to the bottom line and the hinge.

Product logo

To complete the styling it is decided to design a logo for the product.

The approach to create a logo has been that the logo relates to the Hydrema logo, function as a stand-alone and relate to the features of the excavator of the project.

The expression of the Hydrema logo is conservative but the robustness of the letters match the rough context of the construction sites. Hydrema has traditions concerning the company logo that are considered in terms of making the logo suit the current Hydrema logo:

- Graphics and name may not be separated
- The colors yellow and black are for exterior
- The colors gray and black are for interior

ill. 4.6.1. Hydrema logo as used on exterior, i.e. the boom.

ill. 4.6.2: Hydrema logo as used on interior.

Further Hydrema products are marked with a product logo that informs about the functionality and power of the machine, which makes it easy for the operators to relate to the performance capability of the excavator (ill. 4.6.3).

M1700C

ill. 4.6.3

Mobile excavator

17 ton class

Compact model

The design group decides that a product logo of the conceptual excavator mainly has to relate to the features/differences of the concept to make it distinguish from the product line of Hydrema.

The suggestions for the product logo are illustrated at the bottom of the page (ill. 4.6.5)

The final logo (ill.4.6.4) is chosen because it is more similar to the style of the product. It consists of the same elements as the traditional Hydrema product logos, but is using a more modern typeface.

ill. 4.6.4: Final excavator logo

Product logo development

ill. 4.6.5: Logo proposals

Cost allocations

The following describes the considerations of cost prices of the tracks and the counterweight system.

Estimated cost

In the end of phase 4 a cost allocation of the excavator is made and compared to the cost allocations of the M1400C excavator of Hydrema. This is done to be able to evaluate the cost/benefits of the concept according to the manufacturer Hydrema and buyers such as contractors. The considerations mainly concern the counterweight system since this is the elements that are detailed in the project.

Counterweight

The current production of the counterweights in all Hydrema machines is outsourced to a sub supplier and cast in iron. By producing the counterweight of metal sheets and metal scrap the production can be in-house. Hereby Hydrema do not have to invest in mold-tools for the counterweight, which decreases the production price compared to the current M1700C.

Assuming that the E17 sales numbers are similar to those of the M1700C (17 machines sold last year) it is estimated that an in-house production of the counterweight will lower the production price compared to the production price of a molded counterweight. An estimated production price for the counter weight is made. [appendix 7] The price is approximately 15.000Dkr which is evaluated as reasonable.

Tracks system

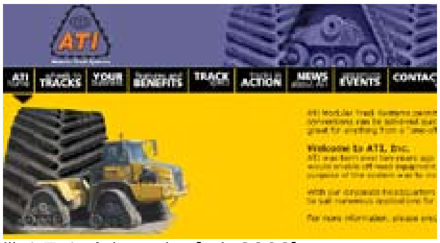
Tracks similar to the excavator tracks are already being produced by Tidue, Mattracks and ATI. (ill.xx)The specific patents have not been found but since the companies are relatively large, so it is assumed that they all have patent rights on the different track systems. Hydrema therefore have following options:

- Produce the tracks and pay the patent fee for the patented parts of the system.
- Establish a corporation with the company owning the patent rights and thereby outsource the whole production of the track system.

It is assumed that the track technology is more expensive than wheels because of an increase in technological complexity

ill.4.7.2. Tidue tracks [Tidue, 2008]

ill.4.7.3. Mattracks [Mattracks, 2008]

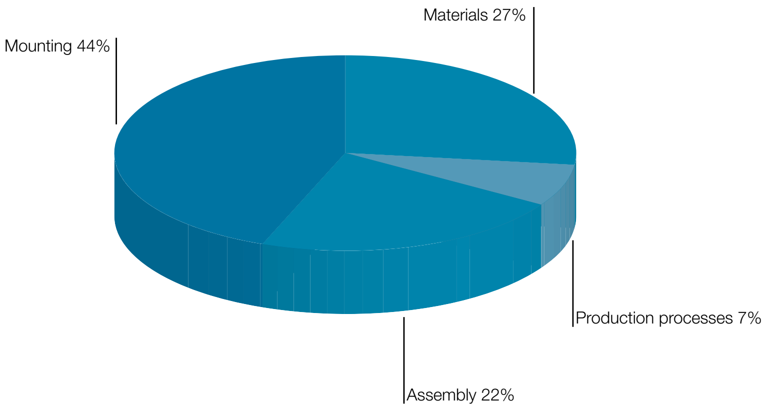


ill.4.7.4. Ati-tracks [ati, 2008]

Estimated cost price of counter weight

Estimated cost price

Materials	7000 Dkr
Production	1500 Dkr
Assembly	4000 Dkr
Mounting	2500 Dkr
TOTAL	15000 Dkr



ill. 4.7.1

and hereby the cost price of the driveline will increase compared to the M1700C. Retail prices found on the internet vary from 80.000 Dkr. to 150.000 Dkr for the tracks. [Mattracks 2008]

Cost allocations of E17

Following cost allocations are defined according to the cost allocations handed out by Hydrema. [appendix 8]

The track cost price is included in the group 3 - Drive line.

For the counterweight, more areas are affected and the counterweight is defined as a separate system part to give the picture of the costs of the counterweight compared to the total costs. The pie charts illustrate the cost allocations of the M1700C and E17. The green areas are directly affected cost groups in terms of the counterweight and the tracks. The blue areas are indirectly affected in terms of expenses for mounting and production.

It is assumed that the total cost of E17 is increased compared to the cost price of M1700C caused by the track system. It is assumed that there will be no extra expenses of the production of the counterweight compared to the current price that is paid to the sub supplier for producing the current counterweight. What is to consider is that an in-house production of the counterweight will require an increase in expenses for man-hours.

Cost areas

1 - Digger: Digger, boom, shovel

2 - Cabin: Cabin, electricity construction, graphics, air conditioning system, hydraulic steering assistance

3 - Drive line: Front axle, rear axle, gear box, cardan shaft, wheels, motor and pumps

4 - Under carriage: Under carriage, dozer

5 - Hydraulics

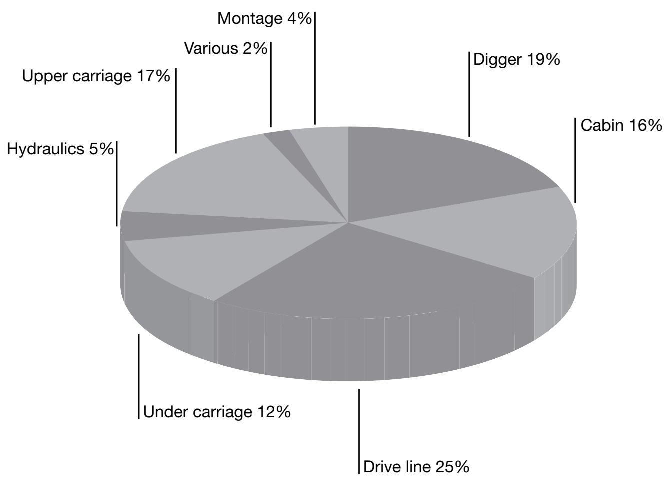
6 - Upper carriage

7 - Counter weight

8 - Variuos: various parts, paintings etc.

9 - Mounting: Mounting, man-hours

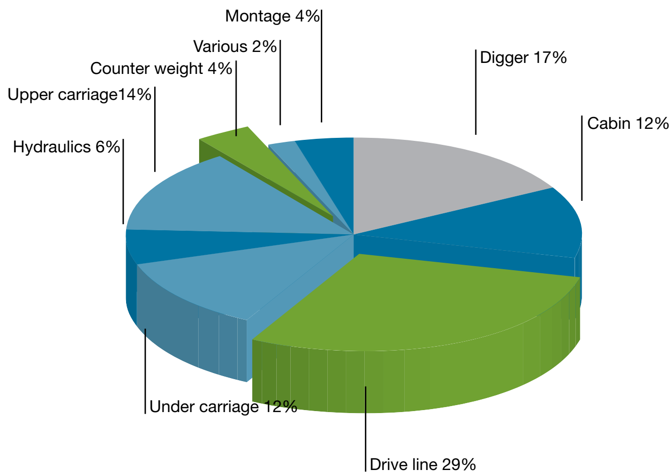
Cost allocations on Hydrema M1700C and E17 respectively



Hydrema M1700C

sale price: 1.029.000 Dkr.

estimated production price: 411.600 Dkr.



Hydrema E17

estimated sale price: 1.029.000+ Dkr.

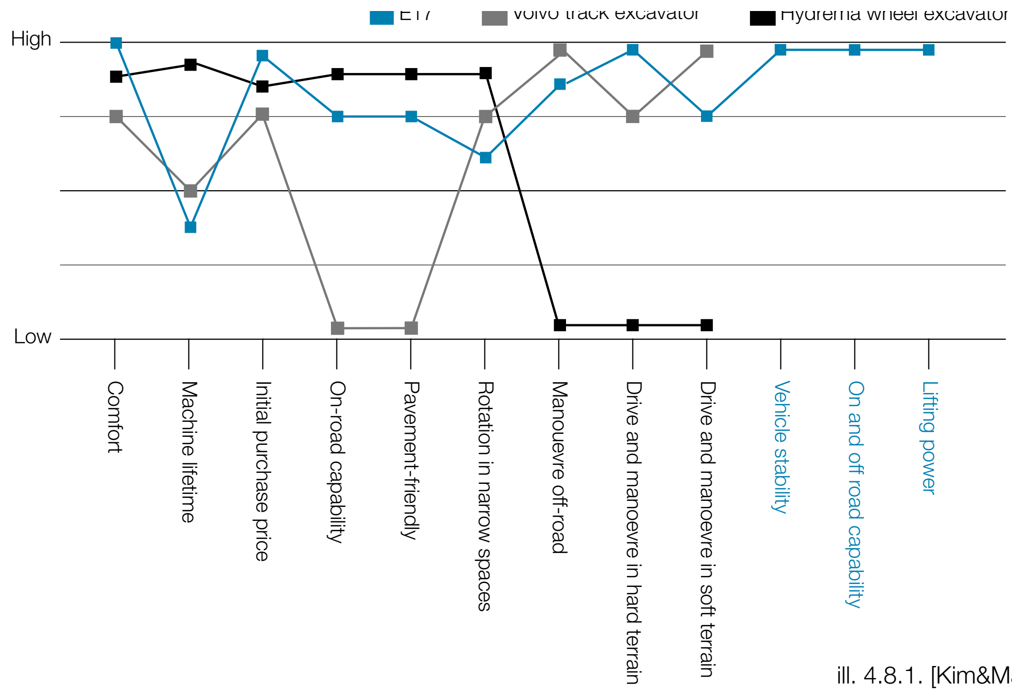
estimated production price:411.600+ Dkr.

ill. 4.7.5

Business strategy

To illustrate how the project proposal separates from the current Hydrema M1700C and tracked excavators of same size and power, the strategy canvas is introduced.

Strategy canvas



ill. 4.8.1. [Kim&Mauborgne, 2005]

The strategy canvas is a mapping of the qualities of Hydrema M1700C, Volvo track excavator and E17. The blue parameters are the parameters added to the canvas through E17.

The Eliminate-Raise-Reduce-Create scheme is the result of disadvantages and the advantages of E17 compared to M1700C.

Outcome

The canvas and the scheme give an overview of the qualities of E17 and hereby an approach to the selling features according to the use of the excavator. What occurs from the schemes are that E17 has improved terrain capability and increased lifting power but is less convenient in narrow spaces because of an increased rotation ratio.

Eliminate

Low rotation radius

Raise

Lifting power

Terrain capabilities

Ability to drive over fragile obsticles

Reduce

Manoeuvre on road

Sustainable for driving on pavements and roads

Compactness

Create

High on and off road capabilities.

Flexibility according to operator use.

ill. 4.8.2

Market scope

Besides the market of demolition, there are applications for the excavator that are relevant for the project proposal and scope of needs.

Designed for city use

Because of the focus areas for this excavator, it is suitable for working in the city compared to a regular excavator. Both because of the 4-tracked undercarriage, but also the small dimensions combined with a counterweight that allows it to take on heavier jobs than similar 17-ton excavators.

Because of these features it is easier for the operator to move the excavator to a new site, without having to wait for the truck. This is an important aspect when working in the city, where the access to the construction sites can be very limited.

It is also capable of entering through small passages without having to put out iron plates to protect the pavement.

Finally it is possible to relocate the excavator to a different location at night, if it is working in places where it could be exposed to vandalism, an increasing trend in the cities.

This allows it to take on a range of different jobs in the city, besides demolition:

Sewers

Many of the excavators observed were working with sewers and piping, and sewer work is an ongoing activity with new drains and renovation of old drains. These jobs often require the excavators to work on streets and roads, where space is limited. Also the excavator is working in situations where the boom is fully extended, why the possibility to control the stability using the tip-down counterweight is a great benefit.

ill. 4.9.1

Renovation

Many old buildings will need renovation or be demolished. These are jobs where it is important that the pavement or tiles must not be destroyed. Considering these conditions, the E17 is a suitable excavator since the 4 tracks distribute the ground pressure on a bigger area, while having a lower friction than regular tracked excavators.

ill. 4.9.2

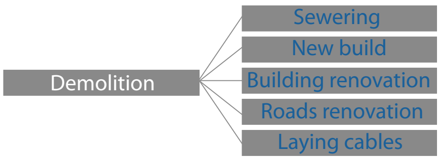
New builds

The excavator is also capable of handling and moving heavy loads, which could be jobs for construction sites, where the trucks was either not able to unload the equipment/material nearby or if heavy material should be loaded onto a truck.

ill. 4.9.3

Full market scope

The sales of minor excavators adaptable to urban areas have increased and will keep increasing due to the urban jobs. Though the E17 design is based on criteria for demolition sites, the improvements are common issues for both construction and sewers as well. The market scope and market potential is therefore obvious, because E17 solves the needs of a niche but also common needs for excavator functionality.



ill. 4.9.4

Cost/benefit

The chapter presents the final concept for an excavator in terms of specifications and cost/benefit.

To be able to evaluate the final concept it is important to be aware of how the concept solution relates to the interests of the stakeholders presented in phase 2. Hereby it is possible to do a final evaluation of the excavator and state the potential markets for the excavator.

Cost vs. benefit

A natural approach is to evaluate the benefits according to the costs of the concept from the manufacturer and the buyer's point of view. This will require that the extra production costs, caused by the tracks and the counterweight, are known to be able to evaluate the benefits for Hydrema. Furthermore it will require estimation from contractors according to the increase of performance efficiency and the saved expenses for preparation, damage and operator working hours.

The design group has therefore listed the assumed benefits for each of the stakeholders.

Benefit	Uncertainties
HYDREMA • Mobility value increased • Positioning at the market for wheel excavators • Possibility of increasing the market to the track • Excavator market	• Raise in cost price? • Increase of sale?
Contractor • Less expenses Damage Preperation Transport • Efficient job execution	• Maintainance expenses (rubbertrack)? • Increase investment?
Operator • Work comfort • Work effeciency • Performance flexibility - lifting power • On/off road flexibility	• Increase of rotation radius?

ill.4.10.1. cost/benefit scheme

Specifications

The previous criteria are gathered in overall specifications for the excavator concept. The specifications are divided in must have, performance and excitement specifications from the Hydrema's POV. This is done to state the important specifications for the concept for a possible further development and production of the excavator concept.

Operator specification

An addition to the specifications is the manual steering of the counterweight.

Interaction

How the operator interacts with the counterweight has only briefly been discussed during the process. A suggestion has been a dynamic motion of the counterweight, where mechatronics controls the expansion of the counterweight corresponding to the need during the use. The solution could have benefits in terms of comfort, but is regarded as an expensive solution compared to the actual need.

There are also certain safety issues with an automatically moving counterweight. Second suggestion has been to activate the counterweight manually. This suggestion is recommended because the operators in most cases are aware of what tasks to perform and hereby also the needed lifting power.

Safety

Safety issues have not been in the scope of the project. However it has been considered that the adjustable counterweight will require an operator manual to guide the operator on which to use in the two modes; compact and expanded, of the excavator. Hereby it can be prevented that the excavator tilts when the powers of the excavator are overestimated. Further it can be necessary to implement and alarm mechanism to warn the surroundings when the counterweight is expanding.

Must have
Product style
Hydrema Yellow/brown
Hydrema logo
Product logo
Function
Digging
Lifting
Moving
Elements
M1700C boom
M1700C internal elements
4-track system suited for 17 ton excavator
Hydraulic system for activating the counterweight

Performance
Product style
Exposure of hydraulics, counterweight and respective elements of the system.
High performance class
max 17 ton
Max height 3900mm
Max width 2500mm
Max lenght 2700mm
Mobility on road
Mobility on road
Max. speed 30km/h
Axle steering
Mobility off road
Increased stability off road
Drive over obstacles without damaging the ground
Stability
Manual adjustable counterweight

Excitement
Product style
Sharp and edgy design (stealth)
Performance flexibility
On and off road capabilities
120-125% lifting power in regular reach without dozer and stabilizers
Production
In-house production of counterweight
Outsourcing of 4-track system

ill. 4.10.2

Conclusion

The following chapter concludes upon fulfilling the learning goals for the semester as well as the assignment from Hydrema.

Learning objectives

Within the project period several tools and methods are used during the process in order to fulfill the goals for the semester.

An understanding of the physical form and function of the excavator is obtained through context research of the work processes, the excavator operators and additional research of the functionality of the excavator.

The project has been managed by using the overall phase plan model of Eppinger and Ulrich. This includes timetables, for the whole project period containing milestones as well as weekly schedules, used in order to control the process within the given timeframe. Furthermore a weekly leader is chosen so deadlines and timetables are reached. Microsoft Office OneNote is used as a digital log, project planner and as well as knowledge sharing between the group members.

Through SWOT analysis, company visits, analysis of the product portfolio, and interviews with customers acting in the market, a profile for Hydrema as a Company and their market is outlined.

Searching in online patent databases is done throughout the project to explore if other corporations have patented a certain solution. Furthermore the patent databases are used to gain inspiration for technical solutions as well as construction details.

An overall concept is made for a new excavator for Hydrema: E17. Simplified calculations are made along the design process in order to estimate the increased potential lifting power caused by the solution. Furthermore the counterweight is selected as a part of the concept for detailing in the last phase. Based on this solution technical drawings are created and production, materials and joints are defined.

A Finite Element simulation is completed in CosmosWorks for SolidWorks and used to dimension and shape the hinges between the counterweight and the hydraulic cylinder. Several solutions are compared relative to each other thereby improving the final design.

The production cost of the excavator is estimated based on cost allocations of the Hydrema M1400C. The cost estimation includes working hours, production and manufacturing. Throughout the process, production cost considerations are used to evaluate the potential of the concept and details.

Hand sketches and Adobe Photoshop is used for renderings of initial concepts. Adobe Illustrator is used for transforming initial hand sketches into digital sketches for accurate dimensions. These sketches are then used as base for a digital model made in SolidWorks. Furthermore SolidWorks is also used for the final renderings of the excavator. Rhino files provided from Hydrema are used to establish an overview of internal elements in the excavator as reverse engineering.

Detailed knowledge of existing models is obtained through company visits.

Hydrema assignment

The overall theme for 8th semester is “Advanced Integrated Design” and Hydrema provided a very open assignment which had to be processed during the project period. The assignment is based on developing a new concept for an excavator. The design proposal is not a radical new concept for an excavator but a concept which improves existing excavators through new features that are not present in the market. The proposal consists of an overall styling, tracks mounted for the undercarriage and an extendable counterweight. The final design proposal reflects the needs discovered among the end users and has a market positioning value through the functionality, expressing it through a solution that is easy to perceive and understand.

Furthermore, the project proposal reflects on some of the key values of Hydrema such as Efficiency, worthwhile and identity creating.

In regards to the rest of the values: Trustworthy, High resale value, Low down time and Retail sale, they depend on the quality of the Hydrema production, together with other departments work inside Hydrema Group. These values are not affected through the project proposal, but will be taken into account when running the design development process, and remind the project group which level to live up to.

The design group delivers a justifiable solution on the counterweight system and the tracks that are based on known technology, with the production facilities at Hydrema taken into consideration. Because of this, it seems relatively easy and financially feasable to do a prototype on the counterweight and thereby be able to test this part of the new product.

In this case, the project proposal is not only targeted at one market niche but solves common known problems for users of excavators which will be the argument for setting the product into production. A future challenge will be to convince the buyer that the added cost and complexity is a worth wile investment in efficiency and comfort.

Reflection

The chapter reflects upon the process of developing the excavator during the project period.

Advanced integrated design

As a new work area for the design group, earth moving industry machines are very complex products to understand, describe and design. The open assignment proposed by Hydrema meant that the design group had to use much of the project time to find and establish a specific problem area to solve. This resulted in lesser time for technical detailing. As a result the project group has spent most of the time in the first phases even though the semester objectives indicate that most of the attention should be paid to the later phases of the plan. The assignment given by Hydrema and the objectives for the semester along with the time frame, are therefore contradicting. Hydrema and their products fit very well into the semester and the theme “Advanced Integrated Design”, but the loosely defined problem assignment given from the start resulted in a lot of research that had to be done in order to research a specific problem for solving during the project. This also meant that the group should have a very good understanding of the whole product which is a very time consuming task in such a complex product. A more specific assignment from Hydrema would have been preferred so lesser time was used for the preliminary phases.

Design in practice

The fact that eight groups are cooperating with one contact person to extract information from did for some periods create a bottleneck in the information flow. This problem was however solved among the groups where a good comprehension of the problem gave motivation for sharing the knowledge obtained in between groups. This was specially seen with the establishment of an online forum with access for the students to shared information, discussions and emails sent to the whole semester.

Along the project period, the design group arranged one individual meeting with Hydrema in order to discuss specific solutions according to the concept proposal. This meeting was very beneficial because it became a discussion where the solution made progress during the actual meeting, contrary to the presentations where the cooperation with the company was more classified more as a regular status seminar at the university. Similar discussions would have been nice during the milestone presentations where the time seemed very short.

Concept development

Throughout the project period, the design group had troubles finding a focus for the project. This is especially seen after the first concept presentation where it was first decided to keep focus on developing the tracks for an excavator. Nevertheless this decision was changed after meeting with the technical supervisor and a revision of how the design group could complete the learning objectives as well as personal objectives.

Along the process it has been an ongoing challenge that the design group had to balance between satisfying personal goals, goals for the semester and goals stated by Hydrema. Often the goals contradicted and led to some discussion of where the project should be heading in order to please the right or the most goals.

Illustrations

Illustrations that are not mentinoed in the list are of own creation.

1.2.1 - 1.2.2: Appendix 8

1.3.1: www.volvo.com/constructionequipment

1.3.2: www.madtracks.com

1.3.3: www.gradall.com/

1.3.4: http://www.listing-ww2club.com/

1.4.1: Appendix 8

1.8.1: www.volvo.com/constructionequipment

2.2.1: Hydrema outhanded on power point slides the 4th of February, see appendix 8

2.2.2: http://n1.cdn.spikedhumor.com/1/530000/125374_12_lamborghini_leventon_1.jpg

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3.6.2: http://www. techdigest.tv

3.6.3: Appendix 8

3.11.3: Appendix 8

3.11.4: Appendix 8

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