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BIM in Bridge Design

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Abstract

Building Information Modeling (BIM) is a relatively new technology and work process. The main idea is to model 3D objects and store the information in a database such that this information can easily be extracted and viewed from these objects. The construction sector has more or less employed full BIM, however, the infrastructure sector has not incorporated the new technology in the same fashion. In this thesis, modeling of a specific bridge structure using the BIM tool Autodesk® Revit™ 2013, and the current bridge design process used at Norconsult were analyzed in order to evaluate the advantages and challenges of using BIM in bridge design. In order for Revit to be applicable it has to be able to accurately design the structure and provide the necessary documentation, as well as incorporate the steps leading up to, and following the bridge design, satisfactory. The main conclusions are:

- There is a future for BIM in bridge design.
- Advantages by utilizing BIM in bridge design have been shown through pilot projects.
- The collaboration of the Revit model with road and underlay models (2D models displaying the projection of a structure on the horizontal plane, used as aid for the modeling of the actual 3D model) for reference is satisfactory, however the road geometry has to be appropriate for BIM purposes.
- The use of Robot was not studied extensively in this thesis; however, non-standard geometry makes the incorporation of Robot difficult.
- Although this thesis does not explicitly investigate the representation of the model created in Revit with other disciplines, there is documentation showing successful interplay in this regard.
- The reinforcement tool included in Revit works well when modeling standard objects, but needs improvements in terms of modeling curved objects.
- In terms of being able to effectively utilize BIM, the skill level of the user is of major importance; in the most extreme cases it can dictate whether or not a task can be done.

Sammendrag

Bygningsinformasjonsmodellering (BIM) er en relativt ny teknologi og arbeidsprosess. Hovedideen er å modellere 3D-objekter og lagre informasjonen i en database slik at denne informasjonen enkelt kan hentes ut og vises. Bygningssektoren benytter mer eller mindre BIM i hele arbeidsprosessen. Infrastruktursektoren har derimot ikke inkorporert den nye teknologien i samme grad. I denne rapporten har modelleringen av en brukonstruksjon i BIM-verktøyet Autodesk® Revit™ 2013, i tillegg til den nåværende bruprojekteringsprosessen i Norconsult, blitt analysert for å evaluere fordelene og utfordringene BIM står ovenfor med tanke på bruprojektering. Dersom Revit skal kunne benyttes som et verktøy i bruprojektering, må programmet være i stand til å nøyaktig representere brukonstruksjonen og produsere nødvendig dokumentasjon, i tillegg til å inkorporere både filmateriale som fungerer som en basis for modelleringen, og filmateriale som skal eksporteres til videre bruk etter modelleringen. Hovedkonklusjonene er:

- Det er en framtid for BIM i bruprojektering.
- Fordeler ved benyttelse av BIM i bruprojektering har blitt vist gjennom pilotprosjekter.
- Samhandlingen mellom Revit og vei- og underlagsmodeller (2D-modeller som viser projeksjonen av en konstruksjon på horisontalplanet) for referanse til modelleringen er tilstrekkelig, så lenge geometrien i referansemodellene er passende for bruk i Revit.
- Bruk av Robot ble ikke studert nøye. Allikevel ble det erfart at ikke-standard geometri skaper problemer ved overføring av modell fra Revit til Robot.
- Denne rapporten undersøker ikke representasjonen av modellen laget i Revit sammen med andre disipliner, men det finnes dokumentasjon som viser at denne funksjonaliteten fungerer tilfredsstillende.
- Armeringsverktøyet i Revit fungerer godt for standardobjekter, men behøver forbedringer med hensyn på buede objekter.
- Ferdighetsnivået til brukeren er en ekstremt viktig faktor i spørsmålet om BIM kan benyttes effektivt; i ekstreme tilfeller kan det diktere om en oppgave kan utføres eller ikke.

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Acronyms, Abbreviations and Terms

Term	Explanation
Civil	3DAutoCAD® Civil 3D™ 2013
Revit	Autodesk® Revit™ 2013
Microstation	Bentley® Microstation™
Robot	Autodesk® Robot Structural Analysis™
Tekla	Tekla® Structures™
Robustness	The objects' resilience towards unexpected and unwanted change when modeling other objects
Flexibility	The objects' ability to be changed according to user preference
Standard geometry	Geometry already defined through the existing objects in the Revit library. This includes slopes and curvature in one plane
Non-standard geometry	Curved and/or irregular geometry (lacking uniformity or symmetry; uneven in shape, position, arrangement, etc.) not already defined in the Revit library
PT	Post-tensioning
PTR	Post-tensioning reinforcement
Rebar	Reinforcement bar

Preface

Through summer internships at Focus Software and project assignment, I learned about BIM (Building Information Modeling) and tools used to perform BIM. I find the field interesting, and am intrigued by the potential BIM has to increase the effectiveness of construction projects. The objective of this thesis is to gain an understanding of the possibilities and challenges connected to representing bridge design with BIM, especially focusing on the reinforcement design. This report is based on:

- The work process in Norconsult and Microstation as an example of how infrastructure projects, and in this case bridge design, is presently approached.
- Civil 3D as an aid for BIM modeling.
- Revit as a BIM modeling tool.

Other companies may use alternative programs, and have a different approach to their work.

I would like to thank my advisor Tor Guttorm Syvertsen for valuable assistance throughout the thesis work. I would also like to thank Focus Software and Norconsult for their cooperation, and in particular Daniel Aase and Christer Wolden, my contact persons in Focus Software and Norconsult, respectively.

1 Introduction

1.1 Motivation

Since its origin in the 1980s, Building Information Modeling (BIM) has been used more frequently as the process itself and the tools used to perform BIM have matured and also as a result of increased computing power. Where pure computer performance previously was the threshold, software and information transfer between different platforms and experts in various domains have now taken its place as the main concerns.

Focus Software uses Revit and Robot for generating BIM-models and structural analysis models, respectively. There are still problems related to designing bridges when BIM is concerned, and in this case Revit. Revit has a bridge construction extension; yet it does not incorporate sufficient functionality for cast-in-place concrete bridges with curvatures and slopes. There is a need to assess the applicability of Revit for bridge design where the geometry of the bridge is non-standard.

Reinforcement of bridges in Norway today is done mostly using 2D drawings, which means that in order to get an overview of the full reinforcement of a bridge one has to combine several separate drawings. With a 3D representation it will be easier and quicker to gain that overview, especially in terms of interference of reinforcement bars. There is a need to evaluate Revit's ability to represent the reinforcement of bridges.

1.2 The idea

Presently, the bridge design process is not well defined in terms of full BIM, and traditional methods are still preferred. Thus, it is appropriate to assess how BIM-tools' lacking ability to design complicated bridges can be remedied and how BIM to a greater extent can be used as a resource in bridge design. By evaluating the process as it is done today and comparing it to a more BIM dominated process, one can gain knowledge about the possibilities and limitations concerning a change in the bridge design process.

1.3 The thesis

This thesis evaluates Revit as a BIM tool, and what advantages, disadvantages and complications both the program and BIM in general holds compared to traditional methods. A central question is whether or not the whole bridge design can be done using BIM tools. Emphasis will be primarily on modeling done with the use of Revit, while also considering the entire modeling process and the interplay with other software. By personally designing a bridge

including the reinforcement of the bridge I will be able to gain a more detailed understanding of the issues related to BIM in bridge design, for further evaluation.

2 Background

2.1 Building Information Modeling (BIM)

BIM is an acronym for Building Information Modeling or Building Information Model. The meaning of the acronym in each case has to be derived from the context. The term BIM has been defined differently by various people/organizations. However, The National Building Information Model Standard Project Committee grasps the core of the term in their definition:

“Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward” [1].

One can discuss whether or not the term *shared knowledge resource* is a correct description, as a BIM contains information from which people can gain knowledge. One may argue there is no knowledge contained in the BIM per se; however it is a resource for potential knowledge. The two most important letters in BIM are I and M; a model is made where the information is available for all the people working on the project. By using BIM, architects, engineers, contractors and owners can create digital information and documentation (e.g. cross sections, elevations and material lists). It is a powerful tool which enables all the actors related to the project to extract the same information and connect to the same platform.

By creating 3D-models and adding information related to all the different disciplines involved (Plumbing, Electrical etc.), all the information which previously had to be coordinated after they were made (sheets describing the bridge used in the construction phase) can be incorporated in the model immediately. This way, one obtains an overview of the project early, which in turn means that problems or improvements can be identified early in the design process. In contrast to traditional drawing and the use of CAD-tools, where the drawings are independent of each other, the BIM is a 3D-model with 3D-objects and elements with parameterized properties and relations to each other. Parameterized properties means that the objects are assigned with certain parameters (e.g. dimensions, offset from original placement, slope etc.) easily altered through a property palette. Once an object is altered, the object will be altered everywhere in the BIM, which renders tedious changes in the

documentation obsolete.

2.2 Bridge design today

The description of how bridge design is presently approached is formed on basis of the work process in Norconsult and the program Microstation. The knowledge acquired was gained through correspondence with Christer Wolden at Norconsult, and also a visit to Norconsult's headquarter in Oslo, Sandvika [2].

There are numerous considerations needed to be made throughout the design. The decisions and designs are made based on previous experiences and expertise, as well as manuals with specifications that every bridge must follow (e.g. the Norwegian manual for bridge design [3] and Eurocodes [4]). Aspects needed to be considered include, but are not limited to:

- Is the project feasible and cost-effective?
- Different specifications: elevations if the bridge spans over a river or a road, road specifications, detailing etc.
- Zoning: the area assigned for the project describing structures already situated in the area.
- Basic data: data of the area influencing the project (height of existing terrain, vegetation, existing technical infrastructure etc.).

3D-model, drawings of profiles, sections and details, plans, reinforcement and material lists etc. have to be established. These documents are generally made separately, and most calculations are made manually.

In CAD programs such as Microstation, the user can model the bridge with a geographically correct position. The engineer usually starts by referencing the terrain and road geometry, which in turn are made according to zoning and basic data. More accurately, the procedure often starts with a road and terrain model in which an underlay including the centerline of the bridge in the horizontal plane is identified, along with road width, slopes, terrain elevations etc. The outer boundaries of the bridge are laid parallel to the centerline. The centerline is, in this thesis, referred to as the line that runs parallel to the bridge's span and divides the bridge in two equal halves. There is no exact procedure when designing the bridge, and the engineer might alter the sequencing of the operations from one project to another. Figure 1 shows a generic workflow of the bridge design process.

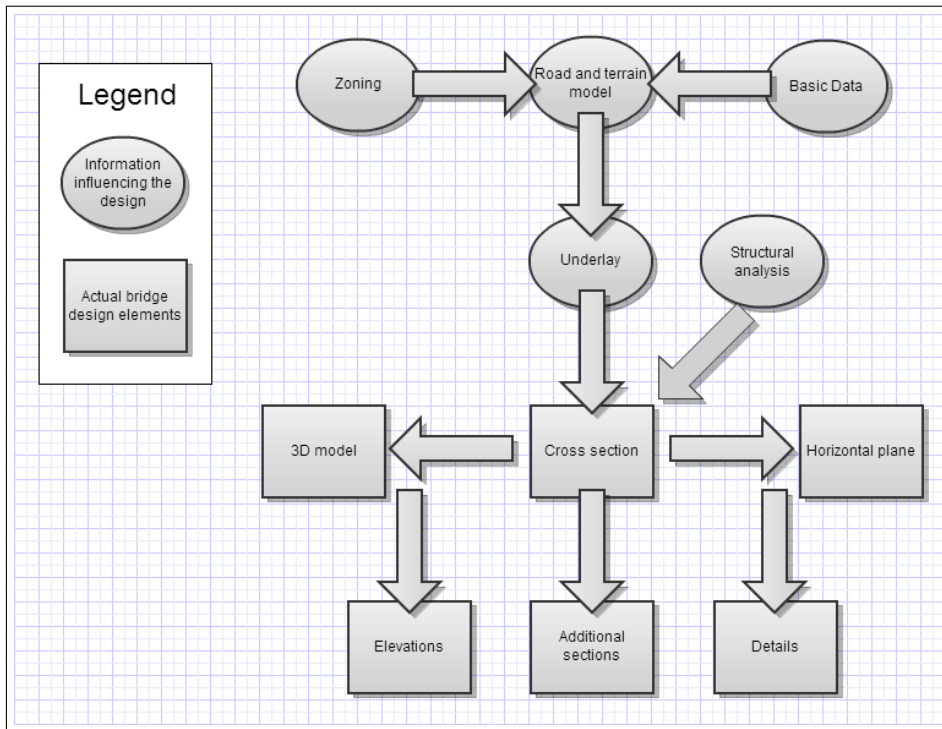


Figure 1: Bridge design workflow

Often, the engineer starts by creating the cross section which in most cases follows the centerline. Then, either the bridge geometry in the horizontal plane or a 3D model is established. Based on that decision, either the 3D model or the bridge's projection on the horizontal plane from the 3D model is drawn, before elevations, foundation and pier details etc. are created. These drawings are so called layers of information, and in Microstation, CAD layers are displayed based on the wanted representation. This way the user is able to, for instance, create an elevation showing only the bridge itself, and another layer showing the terrain surrounding the bridge, and choose whether to show the bridge with or without the terrain, or the terrain on its own.

The required dimensions of the bridge and the reinforcement need are specified by structural analysis, where reaction forces, stresses and strains are evaluated based on pertinent load combinations, both through hand calculations and with the aid of softwares such as NovaFrame and NovaDesign. NovaFrame is used for global analysis of the bridge, while NovaDesign focuses on the forces at given sections of the bridge, which in turn dictates the reinforcement need and the dimensioning of reinforced concrete cross sections. 2D reinforcement drawings are made based on the structural analysis.

Designing a bridge is an iterative process, where changes in the basic data and data received from other disciplines results in a need to update the bridge design. The better the basic data, the fewer changes need to be made through-

out the design process.

2.3 The role of BIM in bridge design

To evaluate the potential role of BIM in infrastructure projects, and in this case in bridge design, one has to address the shortcomings of the present work process. At the same time one has to assess the potential of a new digital process. This includes, among other things, to evaluate the programs used (in this case Revit) and how they can be integrated in infrastructure projects. The construction sector has come to a stage where they more or less employ BIM. The infrastructure sector has, until now, approximated BIM by creating different layers of information (described in “Bridge design today” ??), which in comparison is relatively static and cumbersome. A simple overview of the different stages of BIM is shown in figure 2, where Level 0 is the lowest level of interoperability and Level 3 is the highest. The infrastructure sector in Norway is at Level 1, with combined 2D and 3D representations of the structure without truly any interconnectivity, meaning there are no relations between the different representations. The construction sector is more or less at Level 2, utilizing BIM models with object relations. The aim for this thesis is to determine whether or not Level 2 is applicable for infrastructure projects, and specifically bridge design. The ultimate goal is to reach Level 3 with complete integrated interoperability with a common file format (IFC) and integrated web services, such that all the information stored in a BIM is retained when transferred between programs, and easily viewed through web applications.

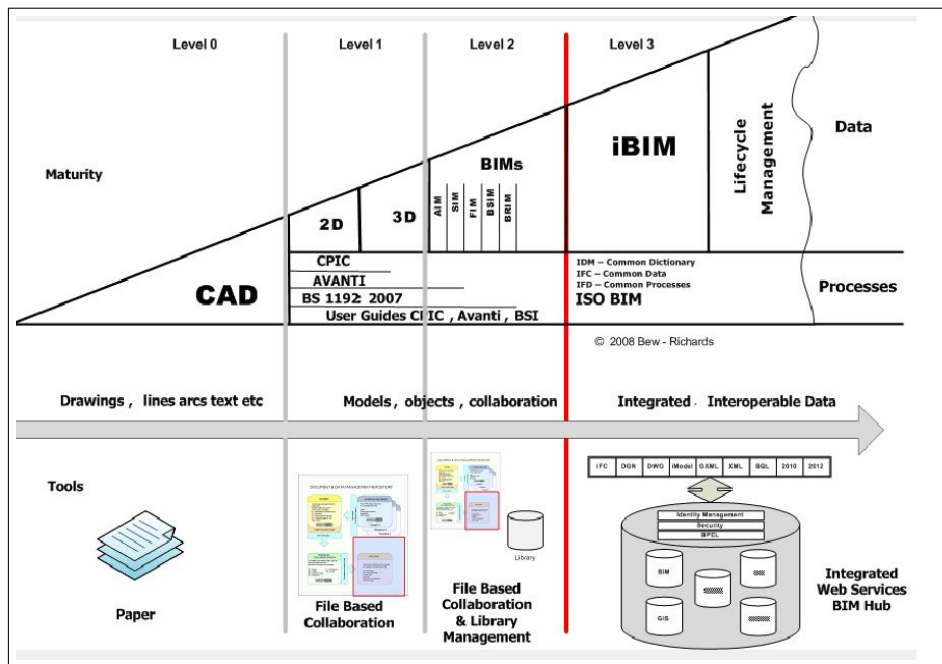


Figure 2: Chart of the BIM stages [5]

There are several reasons why BIM is not utilized in the infrastructure sector:

- No use for BIM; existing CAD-tools are considered sufficient.
- BIM is not demanded by the customers.
- New technology takes time to employ in companies and are often utilized reluctantly. Known and ingrained work processes are hard to change, and gaining competence in new processes are time consuming.
- The BIM-technology still has problems, especially concerning non-standard geometry. The problem with bridges constructed with concrete cast in place is an example of this. Curvatures are often needed in two planes as well as variable cross section. Programs that are not created for use in BIM, such as for example AutoCAD and Microstation, deal with these challenges in a superior manner as they only create the correct geometry without regard to the relations between objects in the model. However they lack the object relations.

Benefits of utilizing BIM have been proved by pilot projects using programs like Tekla and Revit. In these projects accurate 3D-models were created, showing that it is possible to model more difficult geometry with BIM. Laser scanning of existing structures have also been incorporated where additions to the existing structures were to be created.

2.4 Software

The modeling reported here was done in Revit. Revit and Robot are two of the programs Focus Software has specialized in. Microstation is the program used by Norconsult for bridge design. Civil 3D was used to extract the centerline of the bridge from a road model and import this centerline into Revit.

2.4.1 Revit

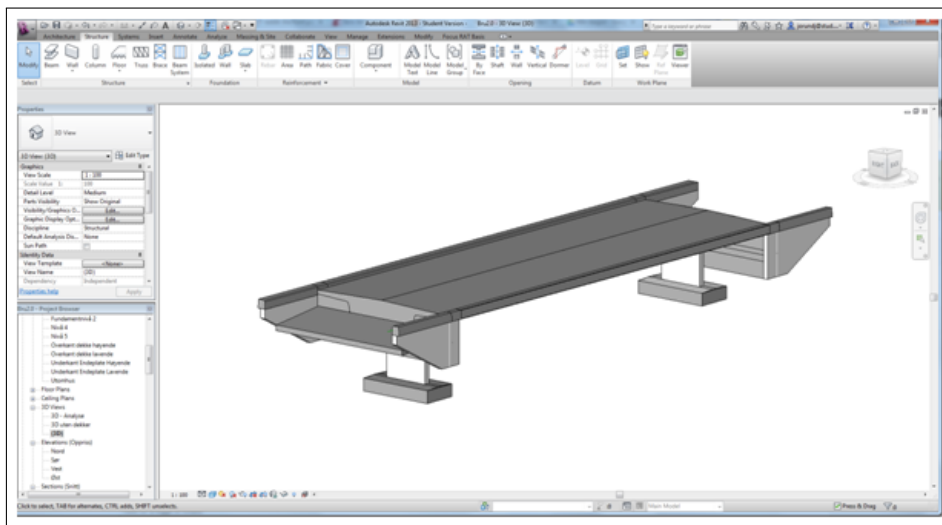


Figure 3: A bridge model in Revit

Revit is a BIM tool which focuses on the design part of the construction process. It has an intuitive and clean user interface, and enables the user to model everything from basic structures to specifically defined geometries. Previously Revit was divided into an Architecture application, an MEP (Mechanical, Electrical and Plumbing) application and a Structure application. In Revit 2013 these applications are combined in one application. Revit's file format is .RVT, but it can also export to and import from the file format IFC, which is the standard format for BIM.

2.4.2 Robot

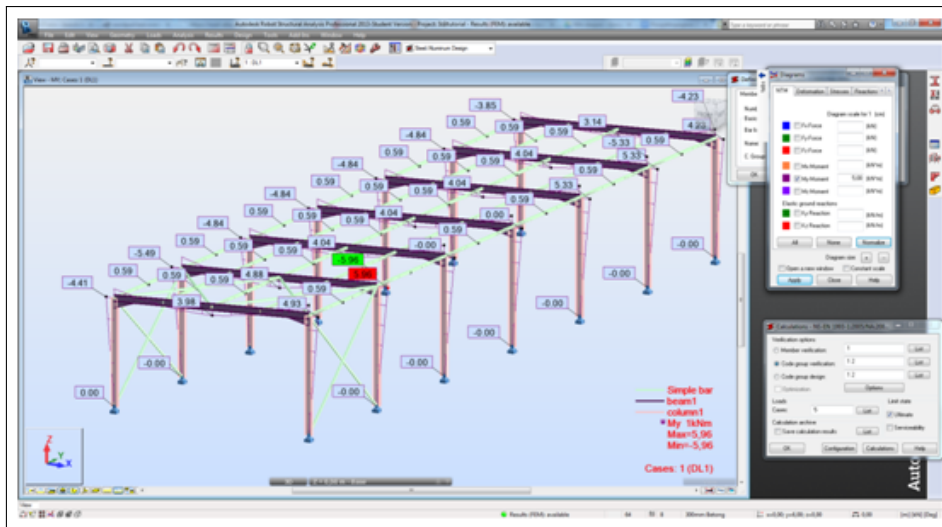


Figure 4: A structure analyzed in Robot

Robot is Autodesk's FEM structural analysis program. There are a number of programs that handle simple static systems, but Robot is made to analyze large and complicated structures. This, and the fact that Robot is connected to Revit in the sense that it can transfer models to and from Revit, makes it an important tool. Models made in Revit can be transferred to Robot for structural analysis, and changes made in Robot can be updated in the model in Revit. A typical example is the use of Robot to calculate the need for reinforcement bars, which in turn is updated in Revit to show the reinforcement bars in the model. In Revit, the changes proposed in Robot are available for review by the user, who can choose whether to execute all the changes, some of them, or propose entirely new solutions. This functionality is important, especially in practice, where different people often work with the two different programs. This allows for the Revit specialist to send the model to the Robot specialist without having to create the analytical model over again.

2.4.3 Microstation

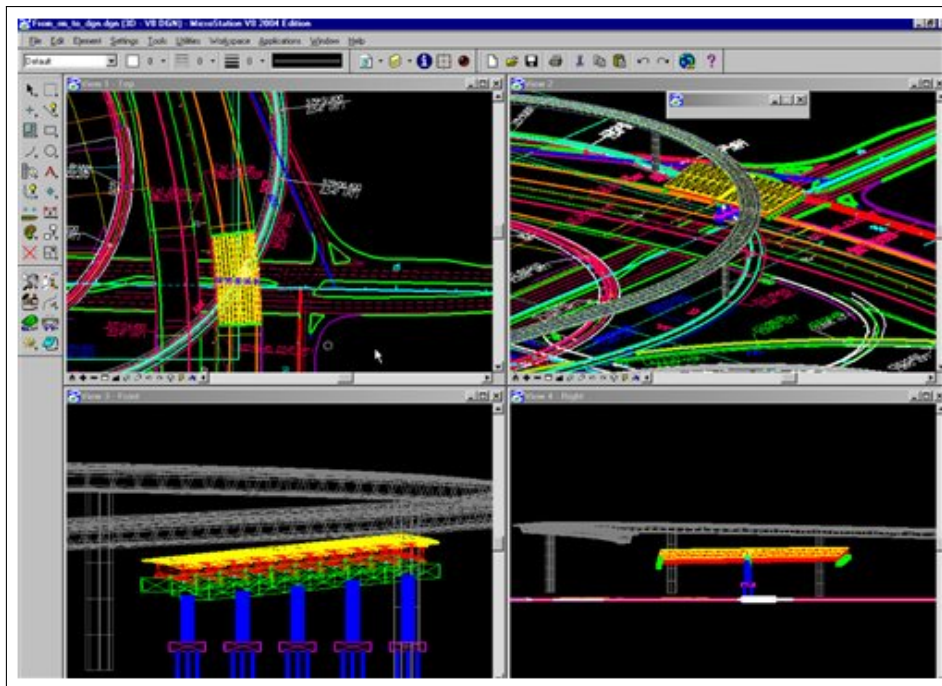


Figure 5: Different views (layers) of a bridge structure in Microstation [6]

At Bentley's webpage Microstation is described as follows:

“MicroStation is the world's leading information modeling environment explicitly for the architecture, engineering, construction, and operation of all infrastructure types including utility systems, roads and rail, bridges, buildings, communications networks, water and wastewater networks, process plants, mining, and more” [7]

Microstation enables the user to create the geometry of the construction and the documentation needed for the construction phase. The program is, however, not a BIM tool; it does not include objects with relations to each other.

2.4.4 Civil 3D

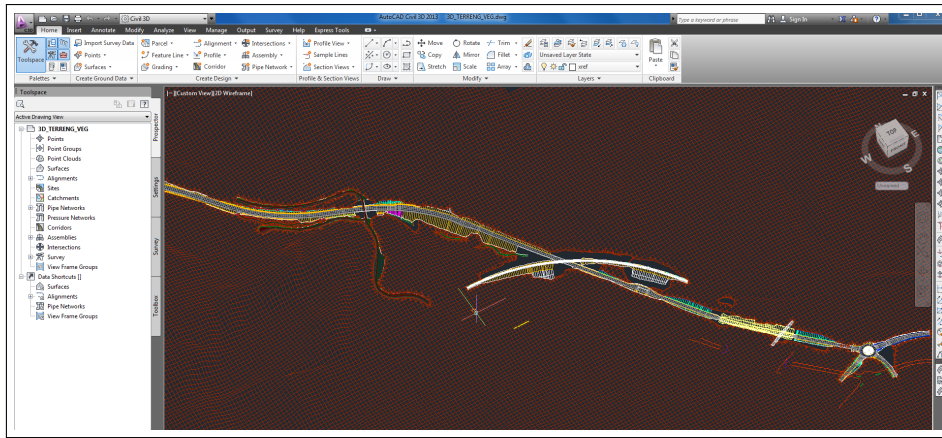


Figure 6: A road model in Civil 3D

Civil 3D is a BIM solution for civil engineering design and documentation. Civil 3D is often used for the creation of bridge deck geometry in bridge design projects. In Civil 3D, the user is able to represent geometry that curves in three planes.

2.5 Summary of the project assignment

The aim of the project was to learn about Revit as a modeling tool and also investigate its applicability for bridge design. This was approached by modeling a simple bridge structure in Revit and assessing the problems, advantages and challenges related to the modeling. Focus was primarily on the modeling itself, but the interplay with other software also had to be investigated in order to evaluate the usefulness of the program. In particular, being able to effectively include a road model and attain the road geometry with the correct coordinates was important. This was relatively easily done with the incorporation of Civil 3D by linking the centerline of the road model into Revit. However, the centerline of the road model was not applicable for use in Revit. The reason behind this was that the centerline consisted not of one continuous line, but several straight line segments attached to each other, creating slight perturbations in the Revit model. The process of importing the centerline worked perfectly, which means that the issue with the centerline was caused by the road model itself.

2.5.1 The first model

The first bridge model was made with the objective of quickly gaining an overview of the complications one would encounter during the modeling of the bridge. As an effect, it consisted of poorly defined objects and solutions, making the BIM lack robustness and flexibility in terms of adapting to changes made later on. It became apparent already in the early stages that the choice of objects in the BIM and modeling procedure were important, and should be carefully considered. The 3D model of the bridge looked correct, however when scrutinizing the model there were multiple errors of unacceptable magnitude (several millimeters). Because of the lacking robustness, remedying errors in one place of the BIM often caused errors elsewhere, making the BIM unpredictable. An example is shown in figure 7, where the vertical dimensions are correct whereas the horizontal are not. If the horizontal dimensions were changed to their appropriate values (200mm and 300mm), the vertical dimensions would also change as an effect of how the object was modeled, leaving the geometry incorrect.

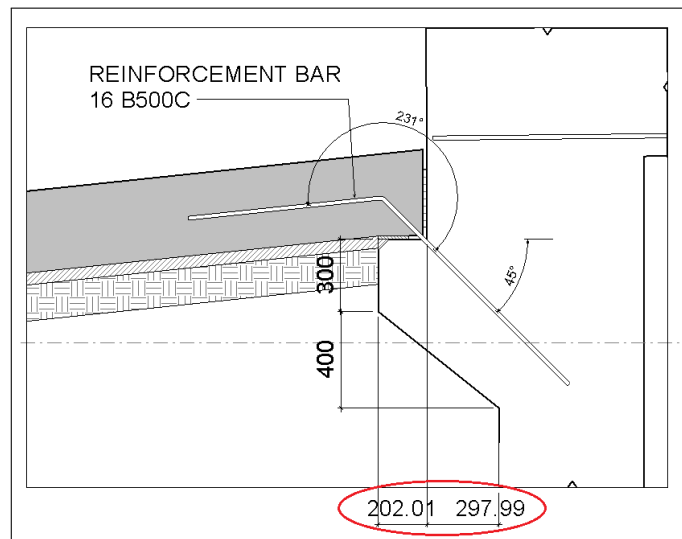


Figure 7: Detail showing errors (dimensions in the red circle) caused by lack of robustness

2.5.2 The second model

With the knowledge gained through modeling the first model, it was realized that before starting the actual modeling of the bridge in the second model, preparations had to be made. New object families were created to attain robustness in the more difficult objects in the BIM. Objects were attached to reference planes and levels rather than to each other in order to avoid having

objects' dimensions and attributes suddenly change when changing those of another object, which was an issue in the first model.

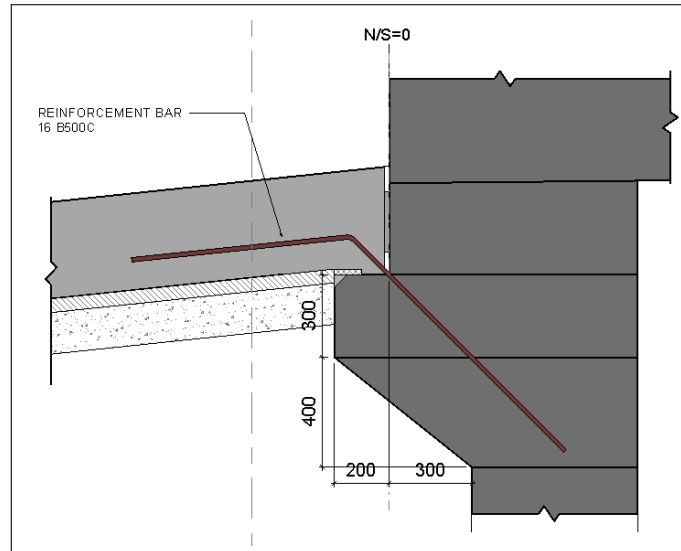


Figure 8: The detail in the second model

With a moderate amount of skill one was able to create a basic bridge model and accompanying drawings, with the exception of the following issues:

- When creating the bridge deck and barriers, there was no convenient way of specifying that they should have a slope while at the same time retain vertical ends. The result was a slight angle at the ends which had to be manually cut, leaving the dimensions of the deck at the ends slightly wrong because of the slope. This problem needed to be circumvented by choosing which sections to annotate; when annotating the abutments in a vertical section one had to leave out the annotation of the bridge deck because of the wrong dimensions.
- In order to view the cross section of the sloped bridge deck and also be able to add annotations to this cross section, the sections which cut the bridge deck had to be perfectly normal to the bridge deck's x-axis (the axis running along the deck's length). This was experienced as a sometimes frustrating task. Focus Software has, after the project was concluded, made a tool for Revit used to automatically create a cross sectional view of an object regardless of orientation. This tool has made the operation a lot easier.
- Railings can only be attached to stairs and ramps, or placed in the horizontal plane. The intention was to attach railings to the barriers, but in

order to do that, new specialized families needed to be created. The result was that attention was placed elsewhere, leaving the issue unsolved.

It should be noted that the level of detail was not the highest in neither of the bridge models, and reinforcement was not studied extensively, because the main goal was to get an overview of the big picture, and also because trivial, yet tedious operations were neglected. However, the bridge as a whole was relatively accurately represented. Slightly inaccurate dimensions in the second model arose mostly due to rounding errors or minor modeling inaccuracies, and were in the range of a few millimeters at most. When operating with millimeter precision, this is also unacceptable. However, the errors were easier to fix than in the first model due to superior robustness.

An important thing to mention is the fact that the ways of representing the model have to be reconsidered when operating with BIM compared to traditional 2D drawings. The BIM consists of actual objects, and one cannot simply alter the representation of the objects in a 2D view without altering the whole model. In traditional design using multiple 2D drawings one sometimes change the position or altitude of certain elements in the drawing to make it look cleaner and more legible. Also, for the same reason and also for dimension purposes, cross sections are sometimes shown as vertical in a drawing when they are in fact sloped. This is not possible, nor is it desirable, when working with BIM. Thus, the representation of the model in the drawings needs to be reviewed and the methods used have to be changed. This is a part of the transfer from traditional methods to BIM.

3 Review of pilot BIM projects

Two pilot projects done by two different companies have been reviewed. A third company, WSP Finland, was also contacted but did not respond. This company used Tekla in their BIM modeling work [8].

3.1 E. Pihl & Søn

E. Pihl & Søn (Pihl) is a Danish contractor that performs projects in numerous areas, including large infrastructure projects, constructions and power plants. They list as the world's 133rd largest international contractor [9]. Pihl has successfully utilized BIM in pilot projects in Scandinavia. With the usage of BIM they have provided eye-opening experiences for the people involved in the projects, making them understand the benefits of the new technology. During one of their projects, the construction of a railroad bridge in the heart of Gothenburg, Sweden, Pihl used Tekla as a tool in the reinforcement work [10]. The bridge, a concrete structure designed to withstand heavy loads, required

vast amounts of reinforcement bars, making the reinforcement bars placement difficult.

The project was split into two stages; the first stage included a new span of 450 meters, and in the second stage an existing span of 550 meters was brought down in order to create a new one. The first stage was designed and reinforced entirely by traditional methods, along with the first bridge deck (the distance between two piers) of the second span. The result was 20-25 out of 100 reinforcement bars that had to be reshaped at the construction site for each deck, as a consequence of the difficulties arising from using and interpreting 2D drawings. The rest of the bridge was modeled in Tekla as an addition to the 2D drawings, and the error in reinforcement bars was reduced to 0-2 per 100 on each deck. In addition, on the first bridge deck Pihl spent 23 days on the reinforcement bars work alone, in comparison to approximately 8 on the second deck. Even though some of the increase in productivity can be explained by the season in which the two bridge decks were reinforced. The first deck was created during the winter, and thus naturally becomes more cumbersome. Nonetheless, Pihl states in their report, most of the explanation lies within the incorporation of BIM.

Among the advantages of using BIM in the reinforcement of the bridge deck, there is the possibility of printing out the reinforcement bar schematics and hang them up on the construction site for the people working with the reinforcement bars to see. This lets them get a much better understanding of the greater picture, the 3D picture, instead of having to visualize the reinforcement bars placement based on 2D drawings. Less time is spent discussing the placement of the bars, and more time can be spent actually inserting them. Another very useful tool Tekla developed for this project, based on specifications from Pihl, was a function which enabled reinforcement bars to be ordered to the construction site by selecting and ordering them through the BIM. All the specifications of the reinforcement bars were sent to the manufacturer. Because of this, and by having an improved overview of the reinforcement bar schematics, Pihl could very efficiently plan the ordering of reinforcement bars in a way that left fewer excess reinforcement bars on the construction site.

3.2 Sundt Construction

Sundt Construction is an American full-service general contractor with expertise that spans the entire lifecycle of construction. Within the civil & transportation sector, Sundt has been involved in designing and constructing roads and highways, bridges and interchanges, airports, hangars, and water treatment plants. Sundt has used BIM in bridge design projects since 2010, and use Civil 3D and Revit extensively in both the design of the geometry and the reinforcement work. Sundt also used Autodesk® Navisworks® Manage to create a 4D model of one of the arches, exploring the construction sequencing.

Navisworks Manage is a project review solution that supports coordination, analysis, and communication of design intent and constructability. Information about Sundt Construction and the use of BIM in their bridge design projects was gained through a skype conversation with one of their modeling engineers, Eric Cylwik [11], and from their webpages [12].

In one of their design projects, the renovation of the 7th street bridge in Texas [13], Sundt Construction used Civil 3D and Revit to model the existing bridge with its 12 new precast post-tensioned concrete arches that run the length of the bridge. The arches included complex post-tensioning tendons and lighting elements which needed careful planning. Being able to model these elements in 3D helped Sundt visualize how all these components fit together. The post-tensioning tendons, which curved in all three dimensions, were modeled in Civil 3D before imported to Revit, where the rest of the bridge, including reinforcement bars, was modeled. According to Eric Cylwik, Sundt usually model the bridge superstructure (i.e. the bridge deck) in Civil 3D, which holds superior functionality compared to Revit in terms of the creation of non-standard geometry. The bridge superstructure is then imported to Revit, where the substructure (i.e. columns, foundations etc.) is included. There is not much interplay between the objects imported from Civil 3D to Revit and the objects created in Revit. The user can neither attach to the imported objects nor dimension to them in Revit. However, curvature in general poses problems in Revit, and Cylwik did not consider the lack of interplay as a major concern. He mentioned that, as of Civil 3D version 2014, solid objects can be shown in Civil 3D when imported from Revit to Civil 3D. This way, one is able to bring a section from Revit into Civil 3D, obtain a solid object and document it there. According to Cylwik, Civil 3D is superior to Revit in terms of dimensioning objects with curved geometry. He stressed that both Civil 3D and Revit should be utilized in bridge modeling to effectively represent a bridge structure correctly and include the information needed.

Eric Cylwik was not thrilled with how Revit worked in terms of rebar modeling. It was not very flexible or efficient in general, and in particular, Revit had a difficult time with reinforcing objects that were curved, which caused issues when modeling the concrete arches. Another reinforcement problem with Revit experienced by Cylwik, was the fact that Revit has a concept where rebar can only be created within a concrete object, resulting in an error message when attempting to add rebar outside of an object. However they found an ad hoc solution; if the user groups the rebars in Revit, the rule Revit generates for the rebars is removed, allowing for rebars outside of concrete objects.

The biggest advantage with BIM, according to Eric, is the better communication between all parties. During planning sessions they could visually communicate with their subcontractors to develop a more realistic construction schedule, and everyone better understood both their own task, and the tasks of others.

Another great advantage with using BIM is the more efficient sharing of information. As an example, if the elevations of specific points on the bridge which are not included in the construction documents need to be determined, previously one would have to figure out the elevations and include them on new spreadsheets. Thus, new spreadsheets would need to be created when updates and changes were made. Now, these elevations can be entered into the model and automatically be included in drawings extracted from the model, reducing the amount of spreadsheets.

4 Modeling in Revit

4.1 Revit User Interface

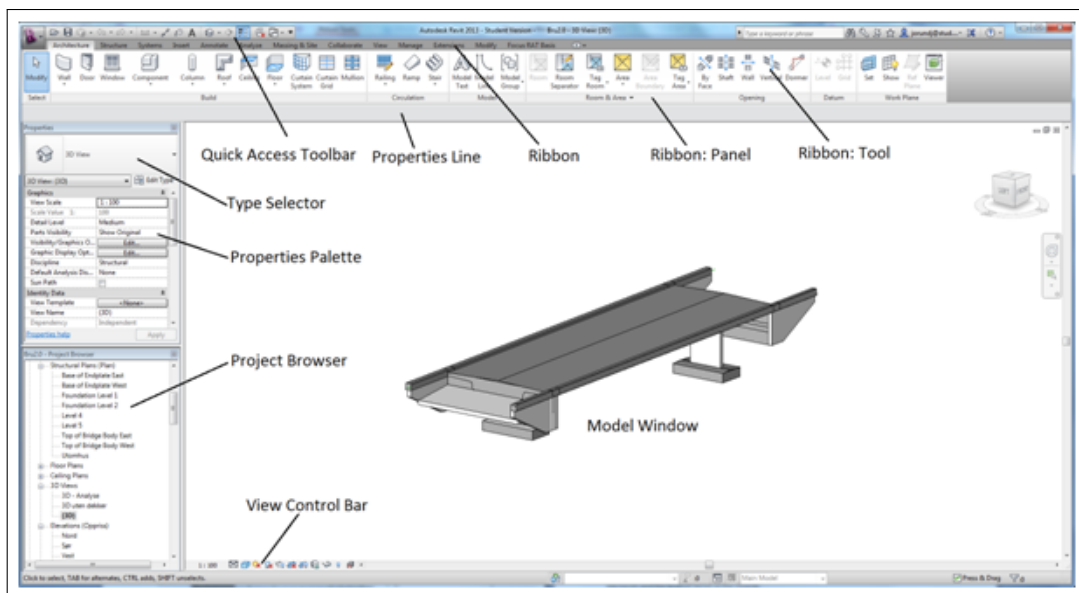


Figure 9: Revit 2013 User Interface

- Tools are sorted in different Ribbons and further categorized in Panels.
- The tools enable the user to perform different tasks in order to create a model which will be visualized in the Model Window.
- The Quick Access Toolbar allows for prompt access to frequently used tools, and the tools displayed in the Quick Access Toolbar can be personalized based on user preferences.
- The Type Selector displays the object currently selected or chosen for creation with customizable properties displayed in the Properties Palette.

- The Project Browser contains all the objects created as well as all the different views contained in the model.
- The View Control bar includes tools for customizing how the model is displayed in the Model Window, including hiding or isolating elements, and adjusting the level of detail of the objects.

4.2 Modeling Basics

Throughout the modeling analysis of this thesis, there are certain elements which will be referred to frequently. Other elements will be explained when needed. Four important elements which are included in any model are the following:

- Object Types
- Views
- Levels
- Reference Planes

4.2.1 Object Types

When describing the modeling process, I will distinguish between three ways of defining the objects used in the model:

- Standard objects: These are the built-in objects that are already defined in the Revit library, accessible through the Revit tools. The objects are categorized in families (e.g. an IPE 220 beam is a member of the beam family). In object modeling terms, a family is a generic class/superclass, and an object is a class/subclass.
- User defined objects: These are objects defined through the families already in Revit. As an example, the user is able to create a new beam family with a different profile than the ones already in the Revit library. The new beam will have beam properties and will be available when selecting the beam tool. The user defined family can be loaded into and used in any project.
- “In-Place Mass” objects: These are objects defined in the model window and are specific to the current model. The “In-Place Masses” are also categorized in families, but they lack some of the properties and modeling operations otherwise attainable using objects already available in the Revit library.

Revit works very well when using the standard objects; these are the objects Revit is mainly programmed to deal with, and the framework of operations available for the standard objects makes for a robust model if created smartly. How well the incorporation of user defined objects in the model works, compared to standard objects, depends greatly on how well the families are modeled. A user defined family without flaws is just as good as a standard family with the exception of the non-standard geometry it may comprise. However, a poorly designed family may cause unexpected behavior in the objects placed in the model, especially when making changes (altering dimensions, aligning it with other objects etc.) to the object.

When modeling user defined geometry, it is very useful to create well functioning families. Not only does this ensure robust and customizable objects, the created families can be saved and used in other projects as well. The importance of reuse of families cannot be emphasized enough, and is especially valid when creating objects that are used often and across multiple projects. The families are then simply loaded into the desired project, where they may be customized according to the needs of that project.

The "In-Place Masses" are the least robust objects; however, they can be useful when objects do not need to be included in a family, and the user wants to create them quickly. In fact, sometimes an "In-Place Mass" is the only object suitable. An example is a void form used to cut another object in order for that object to attain the desired shape when other built-in methods fail to provide the results the user wants. In figure 10, one of the void forms at the abutment wing walls is shown.

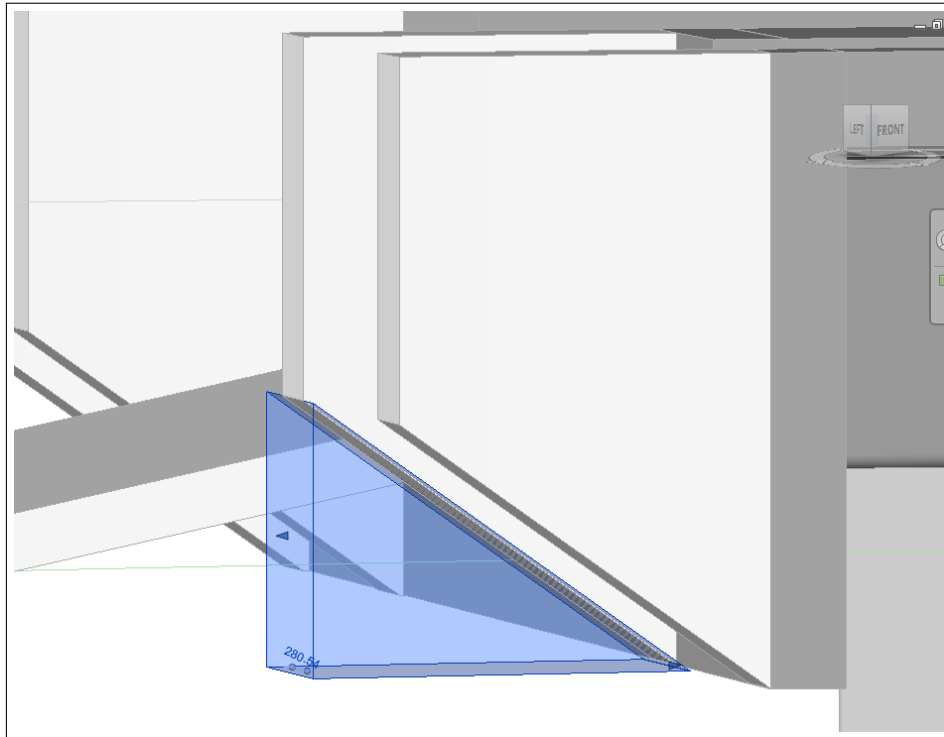


Figure 10: Void form cutting an abutment wing wall

4.2.2 Views

As mentioned in 4.1, Revit consists of different views in which the user is able to work on the model. The default views are 3D-view, elevations, and plan views. The plan views are aligned to the default levels in the model, allowing the user to evaluate the model either looking upwards or downwards from those levels. The user can define multiple 3D-views displaying the model differently or create more levels from which plan views are automatically included. In addition to these views, other views can be created, displaying the model differently or focusing on different parts of the model. There are two types of views used in this regard:

- Sections: Sections are created from within a 2D-view to create another 2D-view. The user is able to specify the view area of the section by defining the direction and the view range of the section. Sections are great when the user needs to evaluate objects from a certain angle (often perpendicularly), and can cut through a model in order to view objects' cross sections. Section views display as section representations in intersecting views.
- Callouts: Callouts isolate a specific portion of the model to show a greater level of detail. The usage of callouts prevents the model itself displaying

too much detail, making it hard and cumbersome to work with.

4.2.3 Levels

Before starting the modeling itself, it is useful to analyze the construction documents and identify important elevations at which levels should be placed. Levels are reference planes visible in the elevation views as well as sections and callouts created parallel to the vertical plane. Objects are often required to be attached to specified base and/or top levels. It is possible to include offsets to objects' base and/or top levels, and sometimes there is a need to have another object as a base or top. However, creating levels as references is a good idea, as it makes keeping track of where the objects are supposed to be situated easier. Furthermore, having stable references increases the model's robustness, and reduces the probability of unexpected errors due to altering of objects.

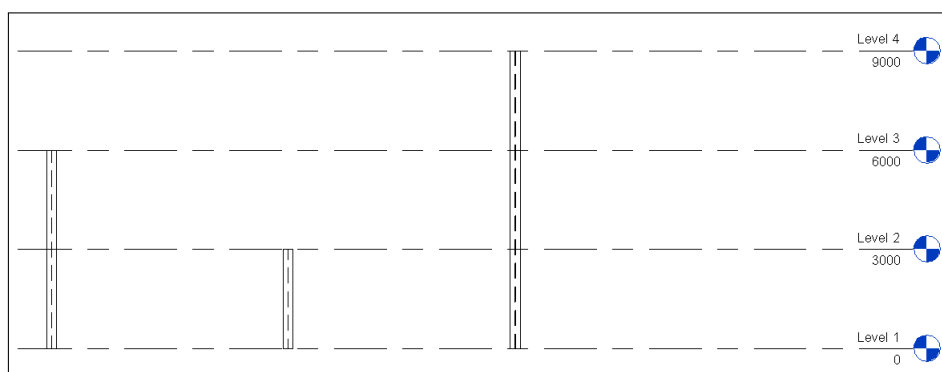


Figure 11: Elevation view including levels and three columns attached to the different levels

4.2.4 Reference Planes

Reference planes are, as the name indicates, a plane used as a reference for objects. They can only be placed in 2D-views as planes parallel to the view direction of that 2D-view, however, as long as they are parallel, the reference planes may be attributed any orientation. Furthermore, if the view direction is defined as the x-direction of the plane, and the normal vector defines the z-direction of the plane, the user can also alter the orientation of the plane in a view with a view direction in the y-direction. Thus, a reference plane can in practice be given any orientation in 3D. In figure 12 two reference planes including dimensions are placed in the same elevations view as in figure 11.

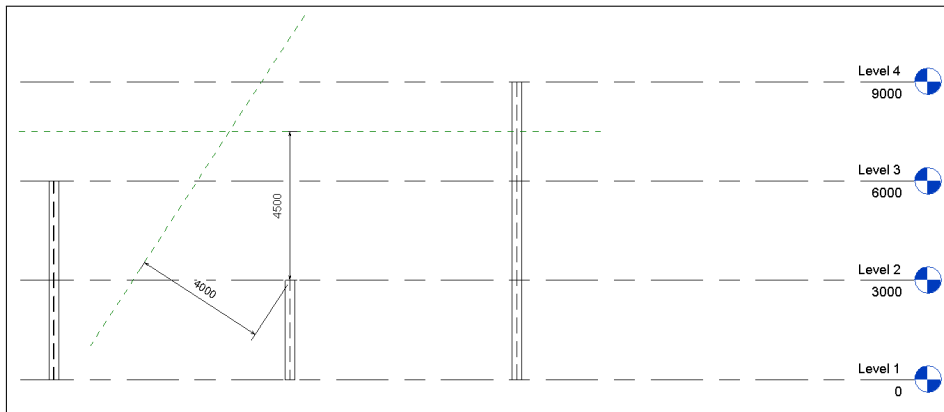


Figure 12: Reference planes

4.3 The Bridge

The bridge modeled as a framework for the evaluation of BIM in bridge design is a three span railroad bridge with a slight slope (1%) and curvature in the horizontal plane ($r=600m$). The middle span runs over a road and piers 2 and 3 are thus skewed compared to piers 1 and 4. The following drawings are received from Norconsult as a part of the basis for the modeling. They are not made in Revit.

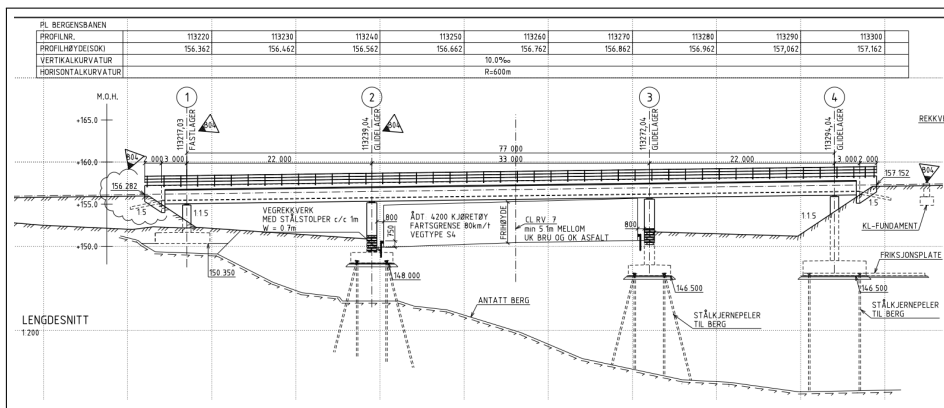


Figure 13: Elevation view of the bridge

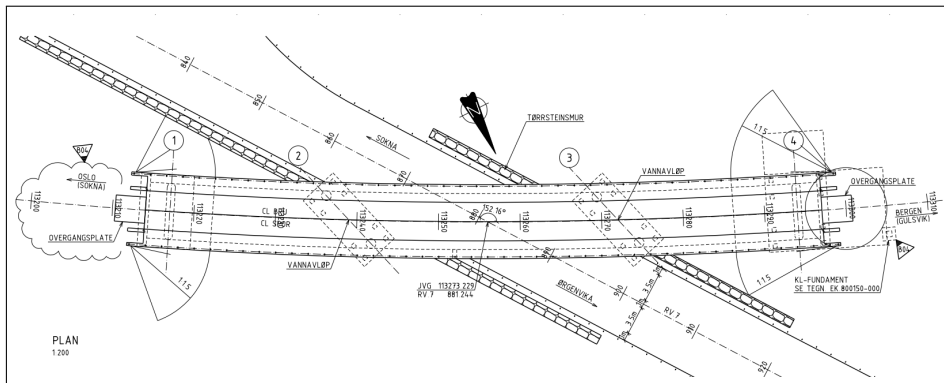


Figure 14: Plan view of the bridge

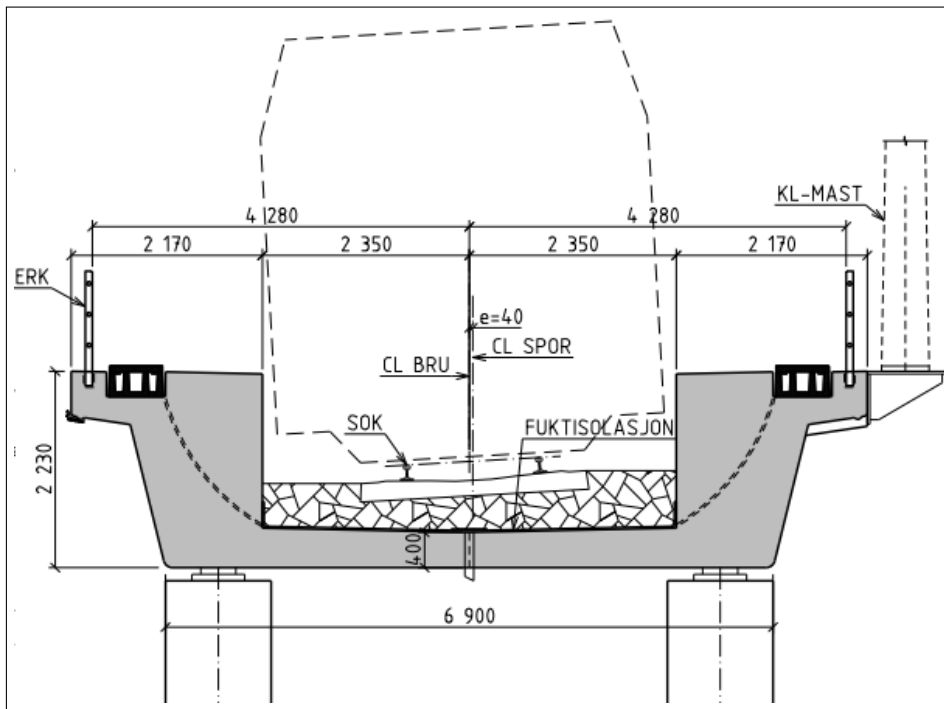


Figure 15: Cross section of the bridge

4.4 Importing the centerline from Civil 3D into Revit

The origin of the bridge model is often the road centerline from a road model in a .dwg file format. A correctly geometrically and topographically placed centerline provides a robust basis for the bridge model, which is extremely important as it sets the tone for the entire design. Civil 3D is a tool well equipped for dealing with road models, which are imported to Revit for further use. The road model received as a basis for the modeling of the bridge in

this thesis consisted of multiple layers which comprised the whole road model. One of these layers contained the centerline. The task of isolating this layer for import to Revit is fairly simple as long as the user makes sure the units are specified to be the same in Civil 3D and Revit. When extracting the centerline from the road model one has to either alter the units within the road model in Civil 3D, or specify the right units during the process of importing the centerline into Revit. The centerline included in the road model received was, in contrast to the one received in the project 2.5, a continuous line segment. However, Revit did not respond well to the very large coordinates of the road model. Norconsult uses the map projection EUREF 89 NTM [14], which ensures that the road model is correctly situated geographically. This resulted in an X-value (North position in the Revit grid) of 6679346005mm. Revit truncates imported coordinate values higher than E9, which resulted in an X-value of about 1000km when acquiring the centerline's coordinates in Revit.

Furthermore, the large coordinates created inaccuracies in the centerline object in Revit. When moving the line to the origin in Revit, it behaved unpredictably, not letting itself attach completely to the origin but instead shifting from either side of the origin when zooming in and out about the origin.

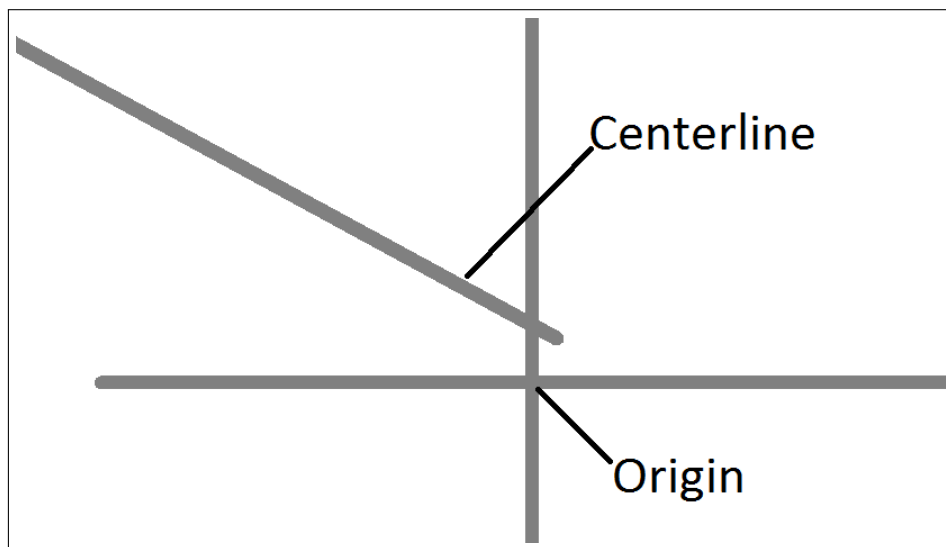


Figure 16: Perturbation at first position

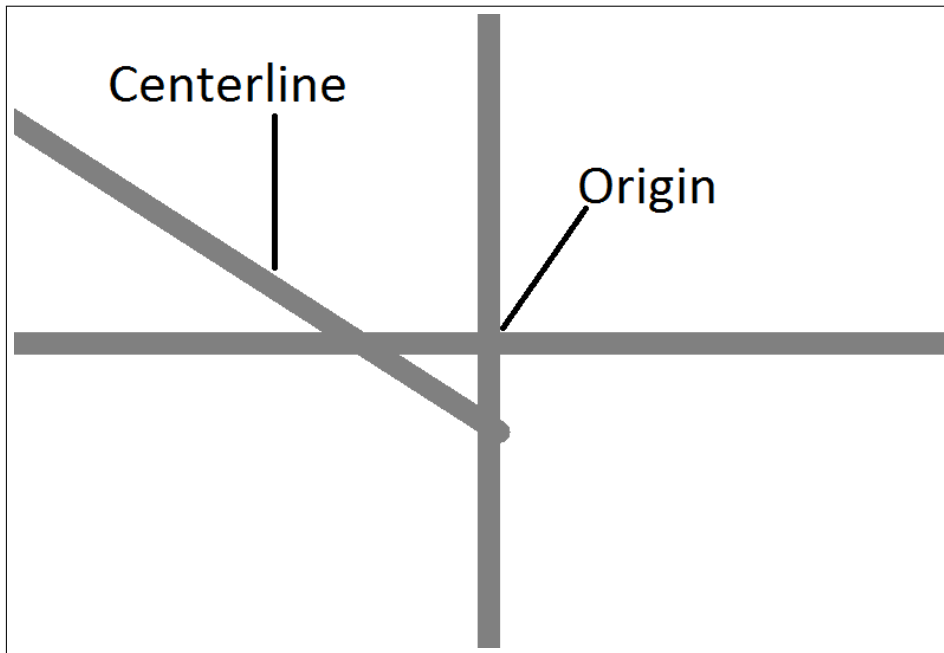


Figure 17: Perturbation when zoomed in

Specifying the correct large coordinates at a point in the model after importing the centerline worked properly, yet it is desirable to be able to acquire large coordinates directly from the imported model without manually altering them after import. However, the problem with the centerline's behavior remained. After some troubleshooting, it was realized that the problem could be circumvented by altering the coordinates in the road model in Civil 3D to 0,0 before importing the centerline to Revit and specifying the coordinates there. This operation removed the perturbation problem of the centerline in Revit. Thus, the centerline could be correctly placed with the right geographical position.

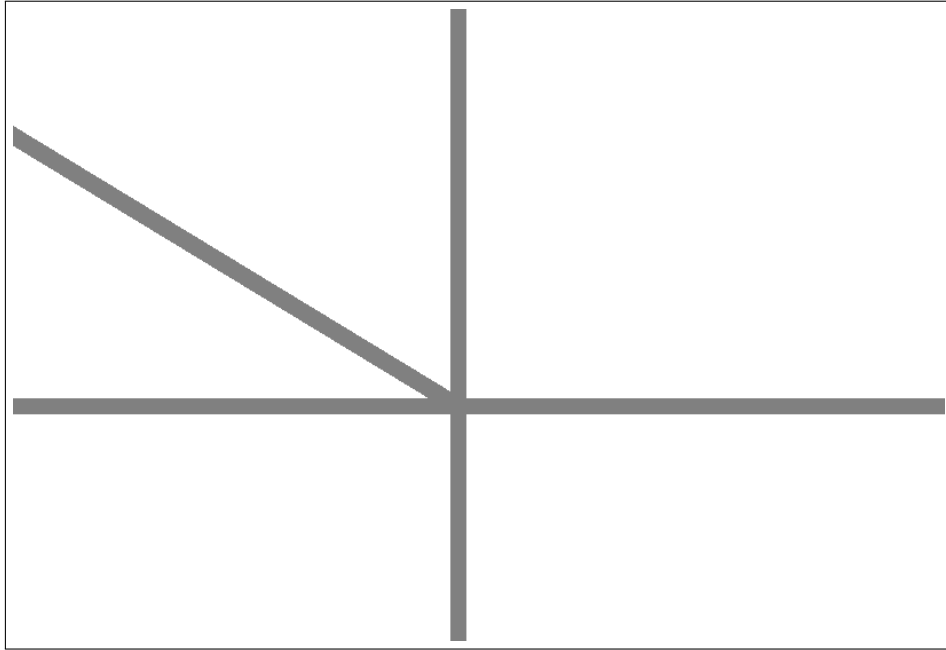


Figure 18: Correct position

The first modeling step included creating the bridge deck profile and using this profile as the foundation for a beam cross section which in turn was used to create a new beam family. The beam family was then used to insert a beam object of that family along the centerline, simply by clicking the centerline while having the beam selected. The centerline imported from Civil 3D was somewhat longer than the bridge itself, and known elevations along the centerline were used to identify the correct start and end point of the bridge in the model. A 2D .dwg file containing the outlining of the bridge including foundations, columns, coordinates etc. was then imported to the model and moved to the correct spot for further detailing of the bridge. The coordinates of this file did not match the centerline's coordinates. This was caused by slight inaccuracies at the ends of the centerline when creating the bridge beam, which resulted in the beam starting with an offset of approximately 15mm in the X-direction and 70mm in the Y-direction (see figure 19) from the start of the centerline. The reason for this was probably a slightly wrong shape of the centerline.

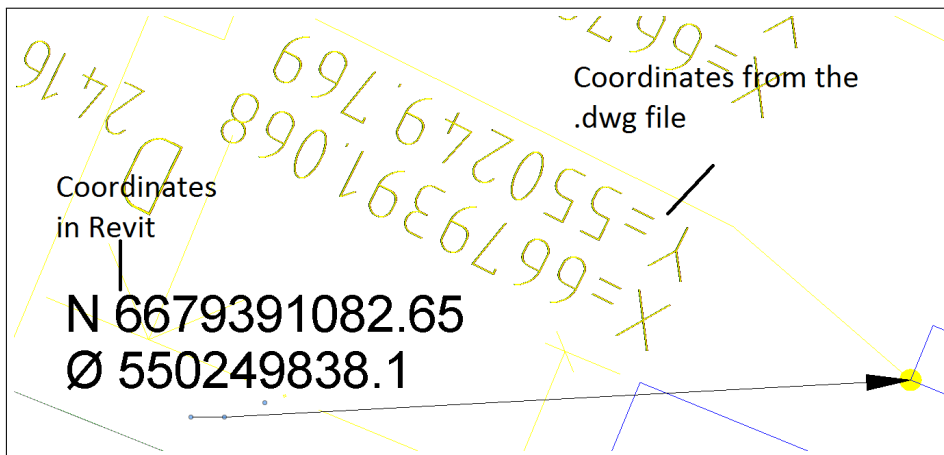


Figure 19: Wrong coordinates, $N=X$, $\emptyset=Y$

Although this effect is not desirable, the problem was easily fixed by simply altering the coordinates of a known point in the model to the ones specified in the 2D-file. In the end it was concluded that the process of importing the bridge centerline was successful, despite the hiccups encountered along the way.

4.5 Modeling the bridge

Figure 20 shows the terminology of bridge components used in this thesis.

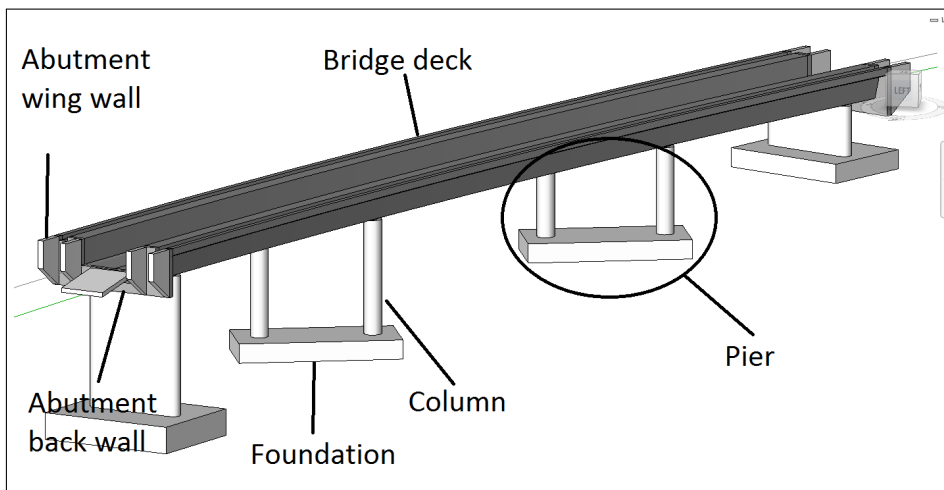


Figure 20: Bridge Terminology

4.5.1 Bridge deck and abutment back walls

As mentioned in 4.4, the bridge deck was created as a beam along the centerline. After some consideration, the abutment back walls were created the same way. To separate the bridge deck from the abutment back walls, reference planes were used at the locations where the bridge deck ended and the back walls started and ended. These reference planes defined the positions of vertical cuts such that the extents of the visibility objects were contained by the reference planes. The objects themselves still had the original extents, but with the exception of some behavior issues (e.g. 5.3), they responded as if they had the correct extents. By creating reference planes one obtained a way to control the extents of the objects without altering them directly, and they could be used as references for other objects to attach to or be dimensioned with respect to. Another reason to model the bridge deck and abutment back walls in this way was that the ends were supposed to be vertical. If vertical reference planes were not used, the objects would have a slight slope at the ends relative to the vertical plane.

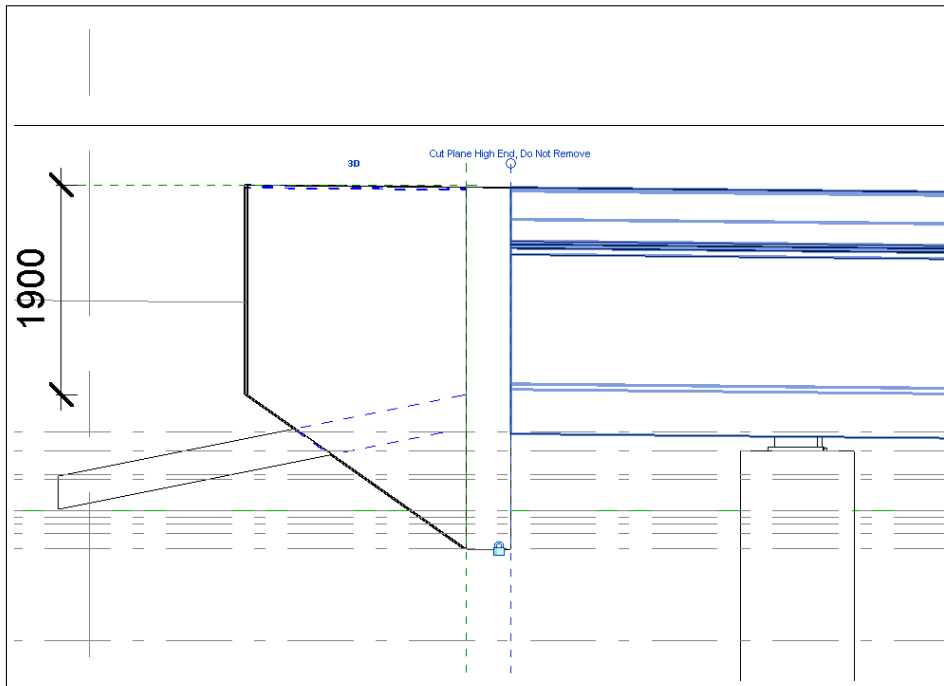


Figure 21: Reference planes cutting the bridge deck and abutment back wall

4.5.2 Columns and Foundations

Mostly standard objects were used in the modeling of the columns and foundations. A new column family was made to model the columns at piers 1 and 4 (i.e. the piers at each end of the bridge), however, this family was quickly

establishable. What posed the most problems were the connections between the columns and the bridge deck. One had the option of creating a new column family with the connection attached, a new family including only the connection, or to create the connections through objects already available. In this bridge model, the connections were simply modeled as a new family consisting of two square cubes, seeing as a correct representation was not important for the model as a whole. If the connections were to be modeled properly, a more detailed family would be needed to display the connection. The question of whether or not to include the connection in a column family would remain. The connection family in this bridge model was not included in a column family. If it was included, one would have to customize the family such that the top elevation of the column could be specified while at the same time leave the connection free to be attached to the bridge deck. This is possible; however by letting the connection out of the column family, the extra work was avoided. Additionally, by modeling the connection separately, it could be added to new columns in a quicker fashion if needed.

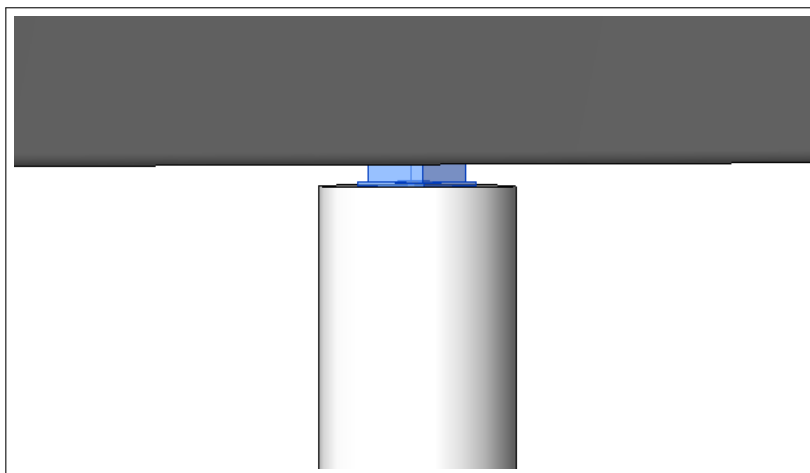


Figure 22: Connection between the bridge deck and a column

4.5.3 Abutment wing walls

There are four wing walls at each end of the bridge, reaching out about 2 meters from the abutment back walls. They were all created as individual wall objects without a direct connection to the centerline, but instead attached to the reference plane defining the end of the abutment back wall. Based on the drawings received from Norconsult, the wing walls curve along with the centerline of the bridge and are supposed to create a smooth transition from the back wall. This caused some modeling issues:

- If a wall object curves, one cannot make use of the “edit profile” tool, which lets the user customize the contour of the wall object as seen from

an elevation view (e.g. 21). The shape then needs to be created through the use of void forms. Void forms are separate geometrical objects hidden in the view unless selected. By letting a void form intersect another object, one can choose to cut the area of intersection from the object. This process is more cumbersome than the “edit profile” approach, and it is harder to create exact geometry.

- The curved wall objects did not always attach to the reference plane properly, resulting in a gap between the back wall and the wing wall.

Using straight wall segments solved these problems, and also made the model more flexible. The question is whether this is an acceptable simplification. The effect of the curvature of an object with a length of 2 meters and a radius of about 600 meters is very small. However, formwork for the wing walls is usually created as an extension of the bridge deck, such that it is actually easier to continue the curvature. Also, the aesthetics of the bridge are improved by keeping the wing walls curved. The user has the option of creating a comment describing that the walls are supposed to curve, but it is not preferable to resort to that solution as the model should be as visually correct as possible. The creation of the correct geometry at the top of the wing walls in order to obtain a smooth transition from the back wall was particularly difficult. As well as having a slope along the length of the bridge, the bridge deck and abutment back walls have a slope at the top in the cross sectional direction. Regardless of how the walls were modeled, void forms were needed to display this correctly. These void forms were not attached to the wing walls or the bridge, rendering them inflexible.

4.5.4 Transition Plate

The transition plate was perhaps the easiest component to model. It was created by adding a wall object with a width of 3200mm, which was the width of the transition plate, to the basic wall family. The wall object could then be placed at the correct position, and with the use of the “edit profile” tool (see 4.5.3), one was able to provide the correct geometry of the transition plate. The ledge on which the transition plate was to be placed was modeled using an “In-Place Mass” created by the sweep tool. The sweep tool lets the user pick or define a 3D path for a 2D profile to follow, thus creating a 3D shape. By defining the bottom edge of the transition plate situated next to the abutment back wall as the path, and creating the appropriate profile, one was able to easily model the ledge object.

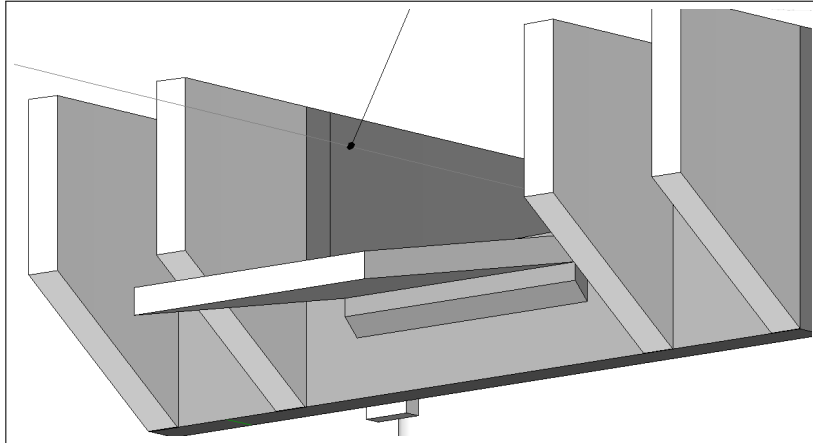


Figure 23: Transition plate and ledge

4.6 Importing the model to Robot

Initially, structural analysis was meant to be done in Robot based on the Revit model. Based on the structural analysis, where appropriate load combinations are included, cross section dimensions and reinforcement need should be determined. Standard objects in Revit caused no real trouble when transferring to Robot for structural analysis. However, when attempting to transfer models with geometries and cross sections not specified as standard objects in the Revit library, difficulties arose. Geometries weren't displayed correctly in Robot and analytical lines used to perform calculations had to be defined manually. When importing the bridge model to Robot, a window appeared where sections which were not defined should be specified (figure 24). Only standard sections were available for selection, thus the sections created for the objects used in Revit could not be used.

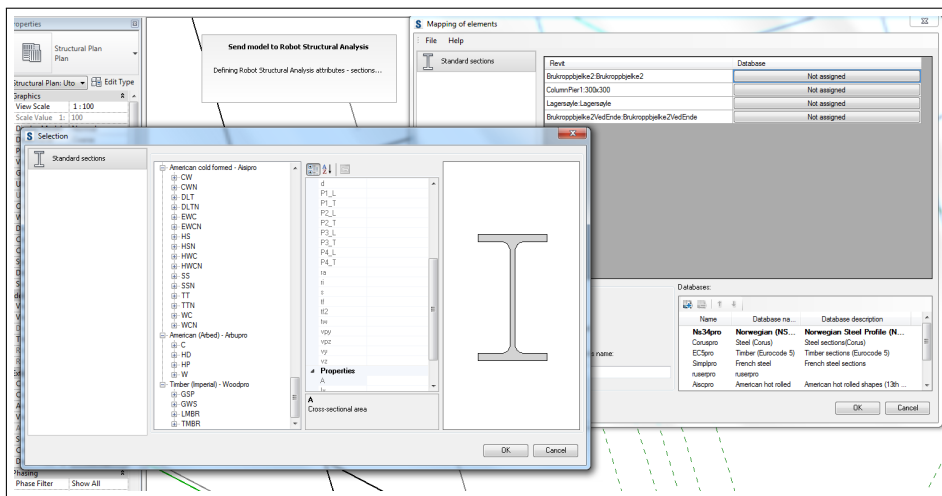


Figure 24: Profile selection when transferring the model to Robot

The consequence of this was that the model in Robot was left without sections for the user defined objects (figure 25), which in turn rendered the model useless for structural analysis (figure 26).

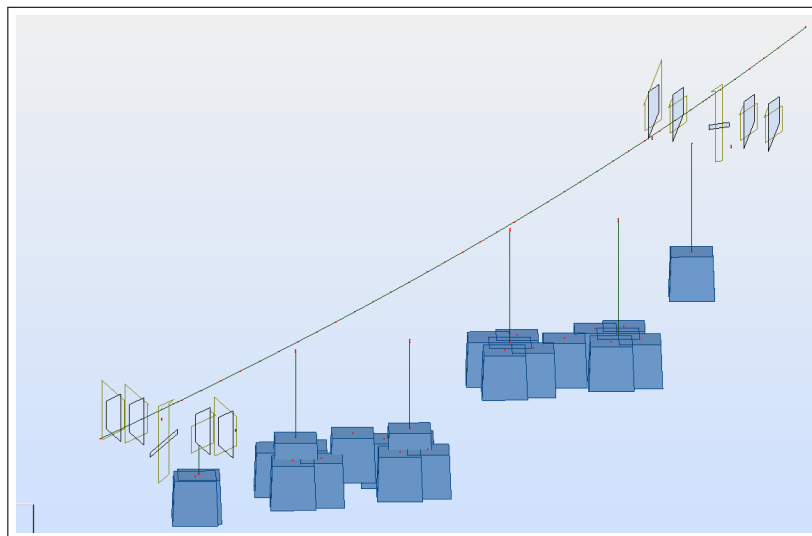


Figure 25: The model in Robot

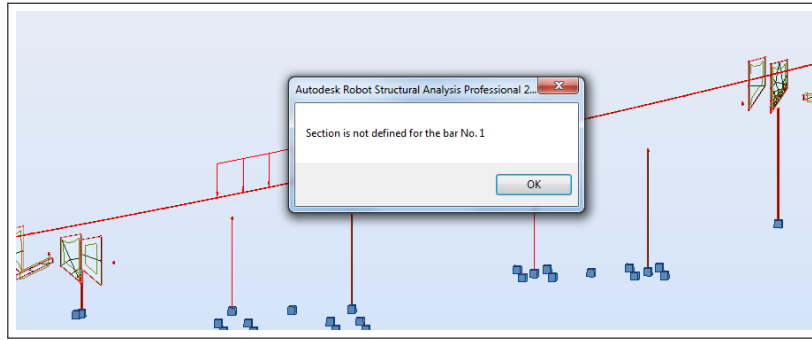


Figure 26: "Section not defined" error when attempting to analyze the model

After attempting different approaches and consultation with Focus Software, the conclusion was that focusing on making a model compatible with Robot would be too demanding. Especially taking into consideration the work needed to assess modeling and documentation in Revit would also be time consuming. Thus, the dimensions of the bridge as well as the reinforcement included in the bridge model were not analyzed in Robot, and the reinforcement was placed solely according to 2D drawings made by Norconsult during their design process (see 2.2).

5 Design Changes

An important aspect of BIM is the relations between objects; by defining connections and constraints, objects behave in a certain way when altering objects they are related to. Which objects are related and how the relationships are defined influences the model greatly when modifying the model. In a bridge project there will be changes throughout the design, and thus a need to make changes in the model. Efficient change management is a highly appreciated feature in engineering projects. A central question is how well Revit is able to deal with changes. Are the objects related to the change flexible enough to behave appropriately, do they behave incorrectly, do they need to be adjusted or do they need to be recreated altogether?

Is Revit flexible enough, and how does different modeling approaches affect the objects' response to the changes? The ideal situation would be having a model where all the objects behaved perfectly to every change according to the user's preferences. This is not possible, both because of lacking constraining possibilities and the fact that while constraining the objects to behave correctly for one change, the very same constraint may prevent the objects from behaving correctly for another change.

Furthermore, there are almost always several ways to perform a task/create the geometry of a model, and how the model behaves when changes are made

may vary depending on modeling choices made before the stage in which the user performs the changes. Thus, in order to achieve a flexible model, the user needs to keep in mind the most probable changes while modeling. In Revit, this is usually approached by attaching objects to either levels, reference planes or to each other. If done correctly, the result is flexible objects that respond to some of the foreseen changes appropriately. This becomes increasingly difficult when dealing with non-standard geometry, especially curved geometry. In order to align objects lines or faces to each other, those objects need to be able to align completely. When operating with curved lines/faces, there are very often slight differences in the orientation of the lines/faces, rendering alignment impossible or causing unwanted results. Sometimes one has to sacrifice some of the authenticity of the model in order to attain flexibility, which is not desirable. The question needed to be asked in this regard is how much the model can deviate from the correct geometry while still being valid as a basis for the actual construction.

Revit may parameterize objects and create smart interplay between objects, but this does not mean adjustments can always be made easily and automatically. One also has to consider whether or not it is appropriate to model for automaticity in each case, since it often requires a lot of time. However, once the changes have been made, the model is updated in all the views in the project, removing the cumbersome process of redesigning the model wherever the change have an effect. Combined with the fact that material usage and other useful information are automatically updated and can be extracted from the model, this provides a great advantage compared to traditional design methods in which 3D and 2D views are created separately.

This thesis includes the testing of the following design changes:

1. Length
2. Position
3. Slope
4. Radius
5. Depth of the piers
6. Orientation of the piers

For each of the design changes one has the possibility of reworking the centerline in Civil 3D before importing it into Revit yet again and create the bridge deck beam along this line. The surrounding objects will need to be reattached, but in some cases this provides less work than customizing them to an altered bridge deck within Revit.

5.1 Length

A change in the bridge length means a change in the bridge deck and abutment back walls objects(1), a positional and rotational change of the piers(2) and the abutment wing walls(3).

1. As mentioned in 4.5.1, both the bridge deck and the abutment back walls were created as beams with the bridge centerline as a reference, and cut at the endpoints using reference planes, removing the extents of the bridge beyond the reference planes. These reference planes can be moved and rotated, resulting in a longer/shorter bridge deck.
2. The piers can be locked in a position relative to a reference plane, making the user able to only change the position of the reference plane when moving the piers and foundations. However, rotating this reference plane did not give the intended results, and simply selecting all the objects connected to the pier and rotating them might be a better idea.
3. How the abutment wing walls behaved as a result of a change in bridge length depended on how they were modeled. Each wing wall was about 2000mm long, and was supposed to curve along with the bridge centerline. They were able to be aligned with and locked to the reference plane cutting the bridge deck. However, when moving or rotating that reference plane, the constraints turned invalid because of the slight angle created between the walls and the reference plane.

In figure 27 the top and the bottom wing wall were created without curvature whereas the middle two were. All of the wing walls are aligned with the reference plane in the first state. Both the top and the bottom wing walls were set to have a length of 2000mm, and the top wing wall was constrained angularly to always remain perpendicular to the reference plane. The reference plane was first moved in order to elongate the bridge before rotated.

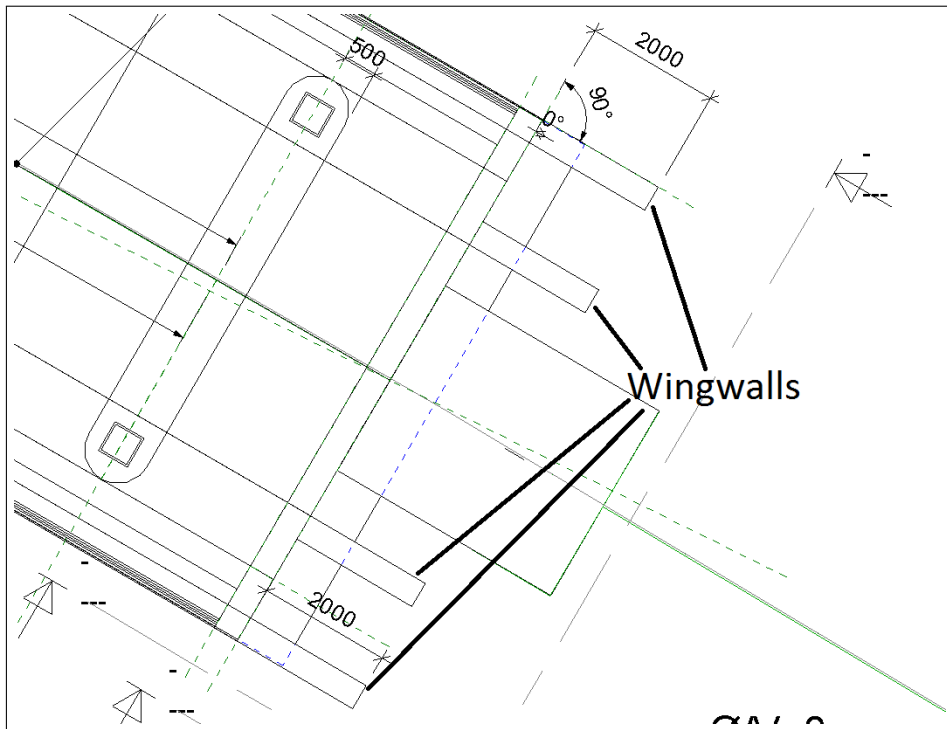


Figure 27: Wingwalls and reference plane at the low end of the bridge

When moving the reference plane the top and bottom wing wall behaved appropriately, while the constraints of the curved middle wing walls were violated.

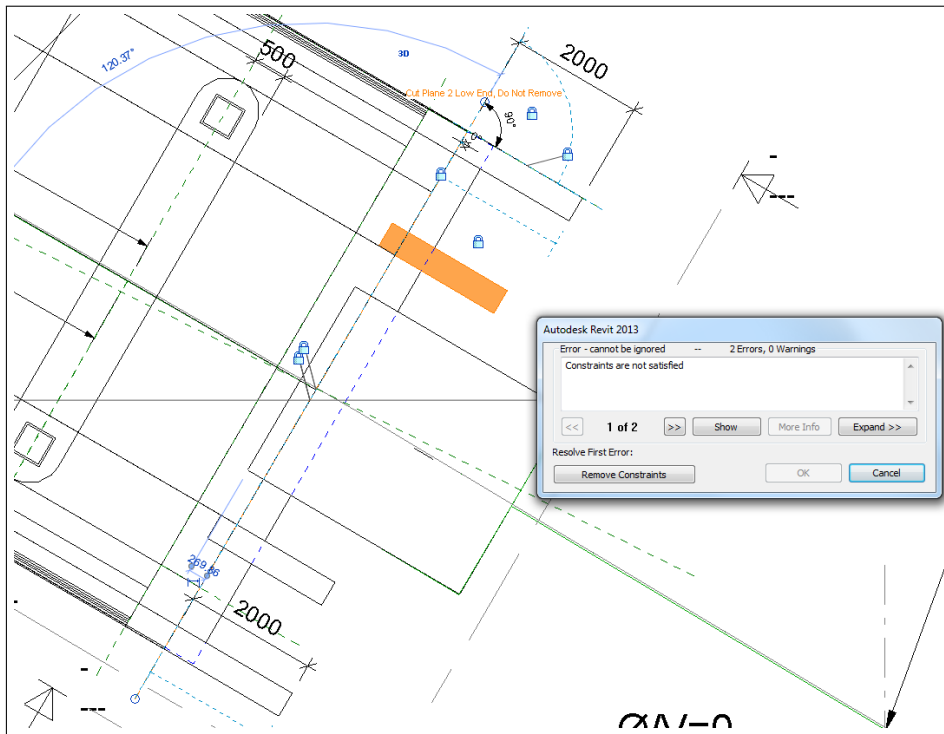


Figure 28: Moving the reference plane

If the wing walls were created without curvature, aligned with the reference plane and constrained angularly, they were able to follow the reference plane appropriately both when moved and rotated. This can be seen in figure 29; after the rotation, only the top wing wall, which was constrained angularly, followed the rotation of the reference plane. The rotation is exaggerated in order to display the effects. An interesting feature discovered in this regard was the fact that if only the top wing wall was constrained angularly, the center of rotation for the reference plane used by Revit was not the one specified by the user. The reason for this remains unclear, but it is not a desirable feature. However, if both the top and the bottom wing wall were constrained, the center of rotation specified coincided with the one used by Revit.

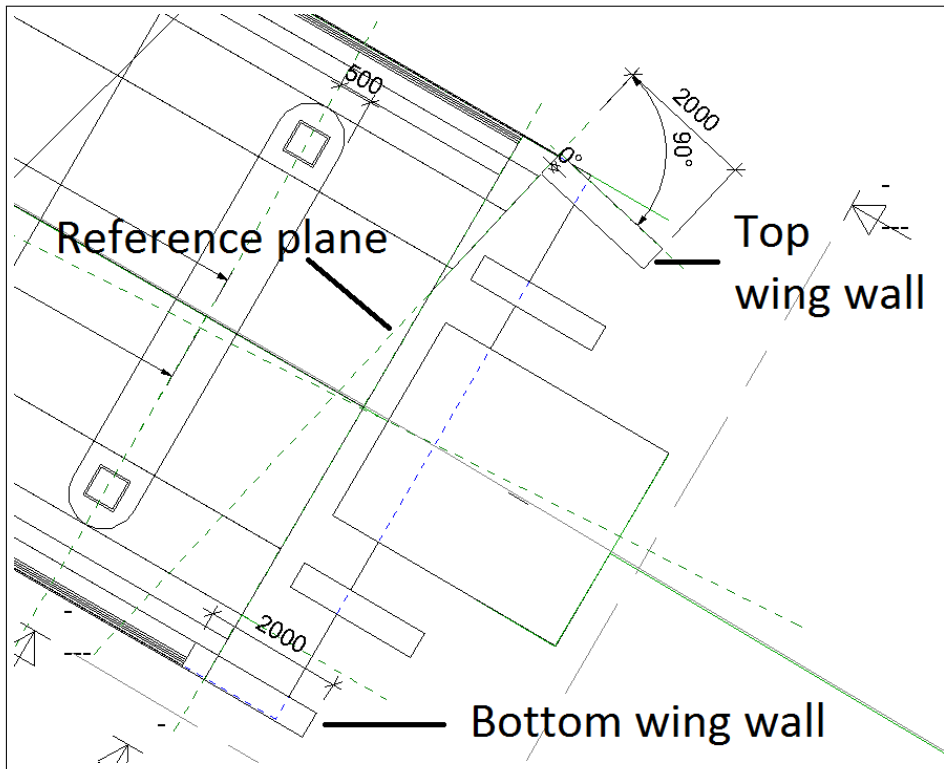


Figure 29: Rotating the reference plane. The top wing wall is rotated

Again the option of selecting the objects and moving them separately is available.

5.2 Position

Intuitively, one might consider locking the bridge in position relative to the bridge centerline file imported from Civil 3D, and use the centerline to move the entire bridge. However, after the bridge deck was created with the centerline as a reference, there was no way of constraining the bridge deck to follow the centerline. As an effect, the imported centerline had served its purpose and was obsolete in terms of usage in further modeling processes. A way of somewhat constraining the bridge deck to the centerline was to create a model line (a line only available to be created in the horizontal and vertical plane which is visible in all views and can be used as a reference for other objects) and constraining parts of the bridge to it. The main problem with this was the fact that one could not align and lock the bridge deck's actual centerline with the model line since the bridge deck had a slope. Thus, the easiest and most logical way to change the position or rotation of the centerline was to simply select the whole bridge with all of its components and move/rotate it. In figures 30, 31 and 32, the blue and yellow lines are the ones included in the

2D underlay file showing the outlining of the bridge, while the bridge itself has black lines.

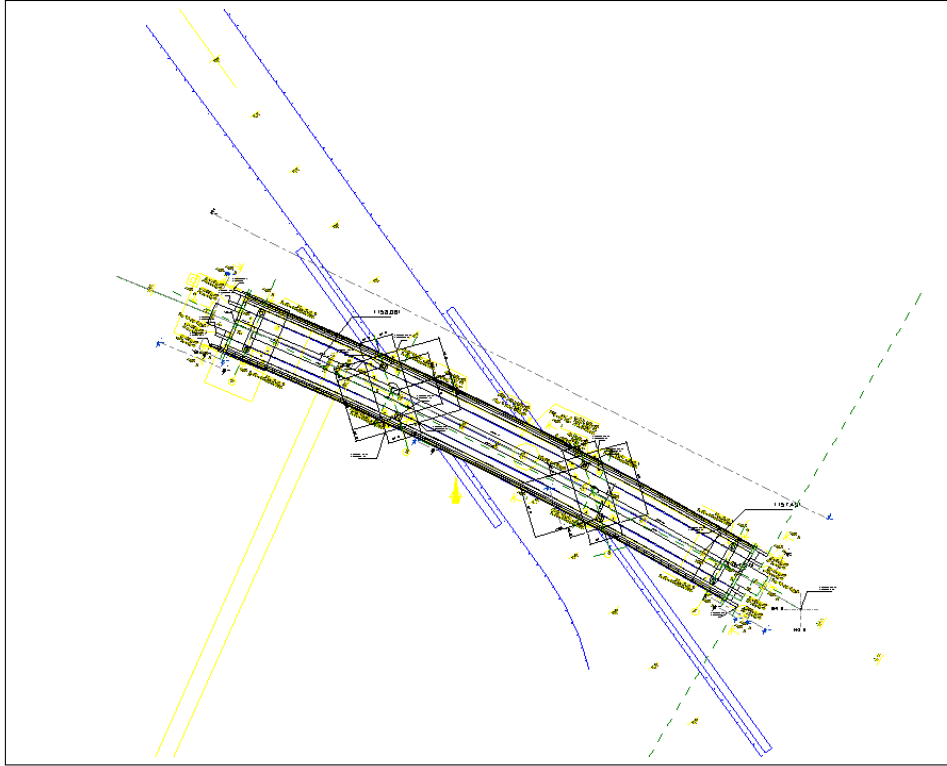


Figure 30: The bridge at its original position

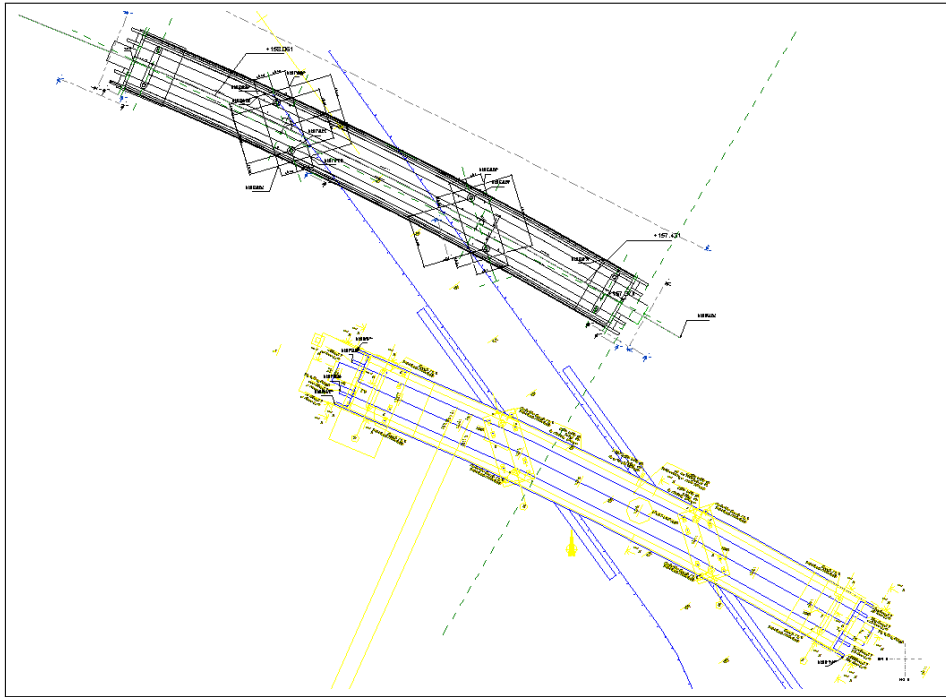


Figure 31: The bridge moved north along the road

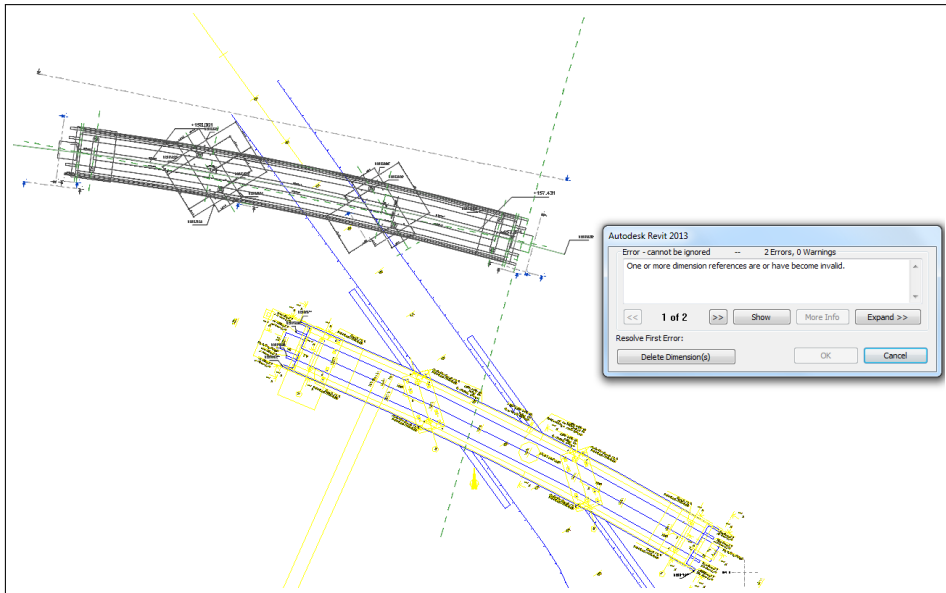


Figure 32: The bridge rotated counter-clockwise

In this case two dimensions became invalid, meaning one or more of the rules which the dimensions need to follow were violated as a result of the change. The user is able to view which dimensions that have become invalid

and decide whether or not to go through with the operation (i.e. deleting the dimensions). Often, the dimensions are not critical to the model, and can be recreated if so desired.

5.3 Slope

A change in the slope of the bridge results in an elevation change at the high end of the bridge. The slope change of the bridge deck itself can be done by altering the elevation offset of the high end, which is a simple task. The problem in this context was that even if the bridge deck's visibility was constrained by the vertical cuts at the ends, the object itself still remained beyond these cuts. The result was that the offset values chosen were related to the ends of the object, not the ends of the bridge deck as it was seen in the model window. Thus, the bridge deck rose at the low end as well. In figure 33 the blue line represents the length of the bridge deck object, which is cut where the abutment backwall starts.

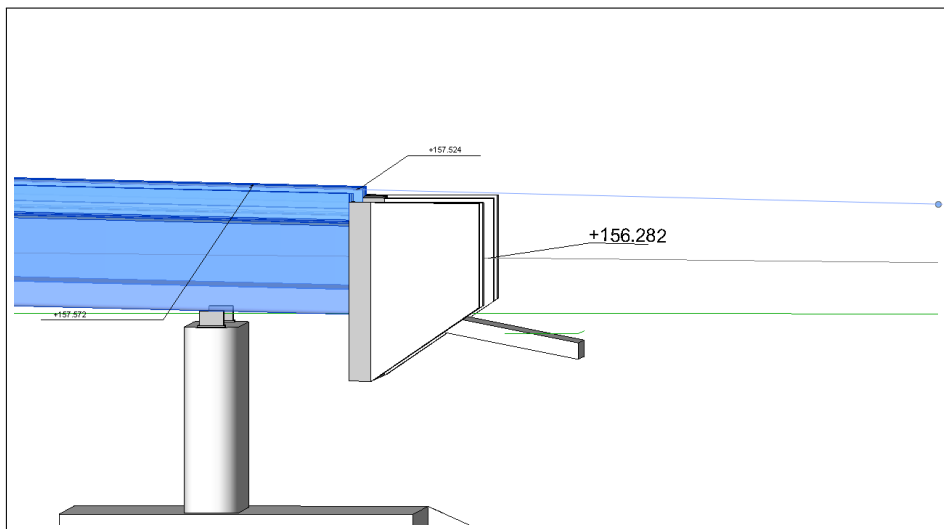


Figure 33: The low end of the bridge rose

A pragmatic solution to this problem is to calculate the offsets which will create the desired slope of the portion of bridge deck between the two cuts. Another is to shorten the bridge deck object to only slightly beyond the cut planes, which will make the difference in offset of the ends of the bridge deck and the bridge deck object almost negligible (the offset can be chosen to be slightly larger/smaller than the actual offset to circumvent this problem).

The connected objects have to be altered as well. Depending on how they are modeled and if they too have a slope, they might have to adopt the slope of the bridge deck. For the wing walls this means a change in profile is needed for

each wing wall. The abutment back walls will need to have altered elevation offsets at their ends too. If objects are connected to certain levels or reference planes, these can be changed to adapt to the change in elevation of the high end. Since the abutment back walls were modeled the same way as the bridge deck, the extents of the abutment backwall objects needed to be set equal to the extent of the bridge deck object for coherency between the bridge deck and the abutment back walls. If not, slight inaccuracies were seen as a result of this difference. A drawback by this approach was that the two abutment backwall objects had the same extents, thus overlapping, which might cause complications when interacting with objects at a later stage. In figure 34 the inaccuracy effect is presented; the left side of the backwall is slightly higher than the bridge deck at the interface between them, whereas the right side is slightly lower.

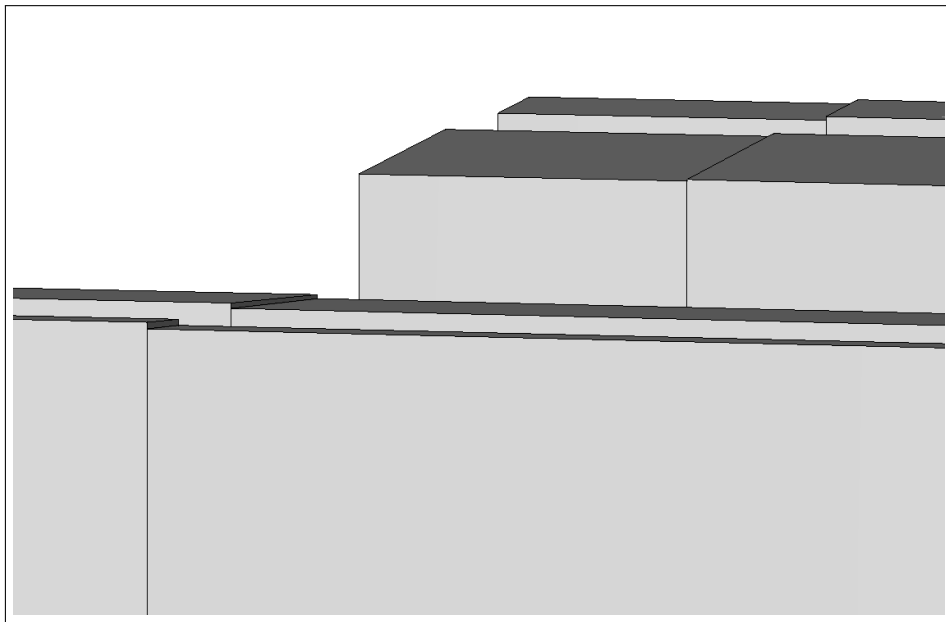


Figure 34: Inaccuracy at the abutment back walls

The operation of changing the slope of the centerline might have been done more efficiently by changing the centerline in Civil 3D. This would remove the need for offset changes of the objects in Revit.

5.4 Radius

This is also a case where changing the centerline in Civil 3D could be a good choice. The abutment wing walls will only need to be rotated in order to remain perpendicular to the ends of the abutment back walls, and the piers will need to be reworked and/or moved slightly no matter how the bridge

deck attains its new radius. Another approach is to create a model line in the horizontal plane with the new radius as a reference for a new bridge deck beam, before setting the correct height offsets at the ends of the bridge deck beam. This is a very quick operation and gives the same result as importing the centerline again. If the height at each end of the bridge deck remains the same, the slope along the centerline will receive a minor change. Depending on the desired slope, the heights might need to be changed as well.

5.5 Depth of the piers

This is an operation very easily done in Revit, as long as the user has defined suitable levels at which the piers can specify their base, and the top of the columns are attached to either a level or the bridge deck with the use of the tool "Attach Top/Base". The "Attach Top/Base" tool constrains an object's top/bottom to another object, such that if the attached object follows if the object it's attached to moves. The only change needed to be done is to set the elevation of the base levels appropriately, and the piers will automatically extend/shorten to adapt to the change. The foundation, which is also attached to the level, will lower such that its top is aligned with the level. The user can also specify offsets from the top and base levels. Another aspect worth mentioning is the fact that if there is a terrain geometry within the model, piers can be lowered to the terrain with the "Lower To Terrain" tool, which is basically a click on a button.

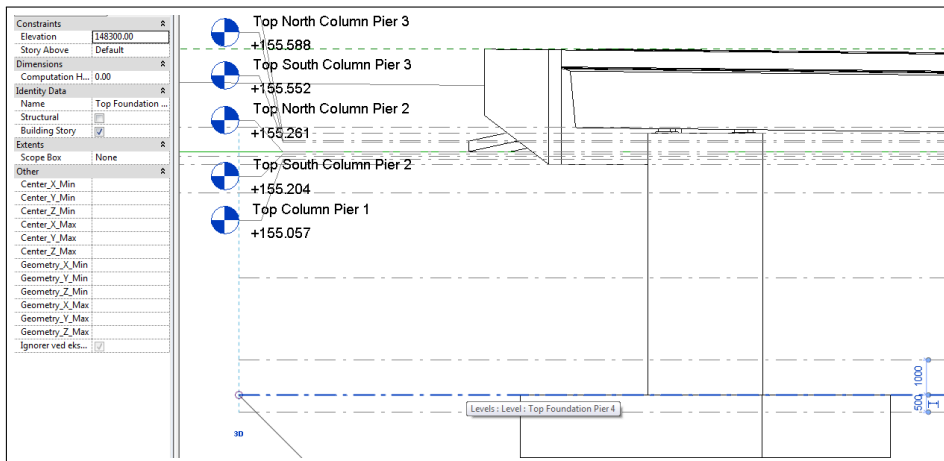


Figure 35: Piers at the high end before the change in depth

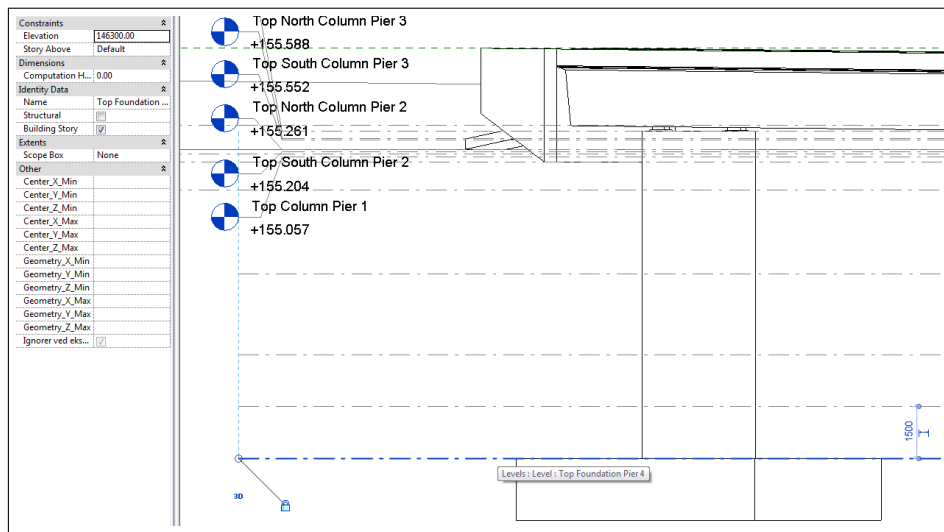


Figure 36: Piers with changed depth as displayed in the field Elevation at the top left corner

5.6 Orientation of the piers

Assuming the superstructure remains the same, the easiest way to do this is to simply rotate and move the given pier to its desired orientation. The best way to do this is to select the components included in the pier in a plan view. When moving the pier, the columns will also move, and the bridge deck above the columns will most likely have a different elevation. If a pier is attached to the bridge deck with the "Attach Top/Base" tool, the columns will still be attached to the bridge deck after the pier is moved as long as the columns are able to intersect with the bridge deck (i.e. as long as the columns are still underneath the bridge deck). The relationship between the objects will stay the same within the pier itself because the objects are all rotated/moved together. However, certain aspects of the relations between the pier and the bridge deck might change and have to be dealt with manually. Dimensions used to show distances, angles etc. between objects in the pier and certain parts of the bridge deck is such a category.

5.7 Summary of design changes

After testing the different design changes, the following conclusions were made:

- It is useful to consider the potential changes when modeling. If the user models smartly, cumbersome manual operations may be avoided. However, when changes which affect a large portion of the model need to be done, it is hard to make all the objects behave appropriately.

- Good modeling solutions take time to establish, but it may be worth it in the long run. The knowledge gained can be transferred to other situations and projects.
- Crude solutions like simply moving and rotating objects manually are often just as good as creating rules for the objects to follow given a certain change, especially if there are few objects that need to be manually altered.
- In the case of a new slope and a new radius, returning to Civil 3D and modify the centerline there could be a good idea. After the centerline has been placed and given the correct topographical placement, the bridge deck and abutment back walls are then reestablished by simply clicking the objects onto the line, and new cuts to these objects are relatively quickly made. This ensures the centerline position is correct, and the same operations would have to be made to the surrounding objects regardless of whether the change was made through Civil 3D or in Revit. As mentioned in 3.2, Sundt Construction usually makes the whole bridge superstructure in Civil 3D. If modeled that way most of the design changes would have to be done in Civil 3D.
- Even if some of the design changes may require as much or even more work in Revit than they presently require in programs like Microstation, the benefit from the automatic update of the changed objects in all views of the model makes the workload less in almost any case.

6 Reinforcement of the bridge

As mentioned in section 4.6, the reinforcement modeling was done on the basis of Norconsult's 2D rebar drawings, which in turn were made based on structural analysis performed by Norconsult (section 2.2). Revit provides good functionality for reinforcement of concrete structures. In the case of standard objects the user is able to quickly establish the basic reinforcement needed in any concrete object through either the area reinforcement tools (for floors, walls or foundations) or Revit's reinforcement extension (for most standard objects). For additional reinforcement and reinforcement of other objects, the user has to utilize the rebar tool, which offers numerous rebar shapes as well as the possibility to sketch a rebar shape for manual insertion of rebar in an object. These tools can be combined; the user may use the area reinforcement tool or the extension to place the basic rebars in the object, before adding specific rebars with the rebar tool. In the case of non-standard geometry, the rebar tool is the only applicable of these tools. Furthermore, when reinforcing a bridge structure which requires a vast amount of rebars, one will always have

the need to add several rebars in addition to the ones placed with the other reinforcement tools.

6.1 The area reinforcement tool

This is a neat tool for quick reinforcement of standard floors, walls and foundation slabs. With a simple click on the tool Revit automatically populates the selected floor, wall or foundation slab with rebars, customizable through the properties palette 4.1. In figure 37, a floor reinforced with the area reinforcement tool is displayed. The tool creates rebars in both directions at the top and bottom of the object. In the properties palette to the left, the user can specify rebar diameter, hooks at the ends, major and minor rebar direction and spacing between rebars in the four rebar sets. A tag, which can be seen in the plan view, is automatically included (38) and will change if changes are made to the rebars in the area reinforcement.

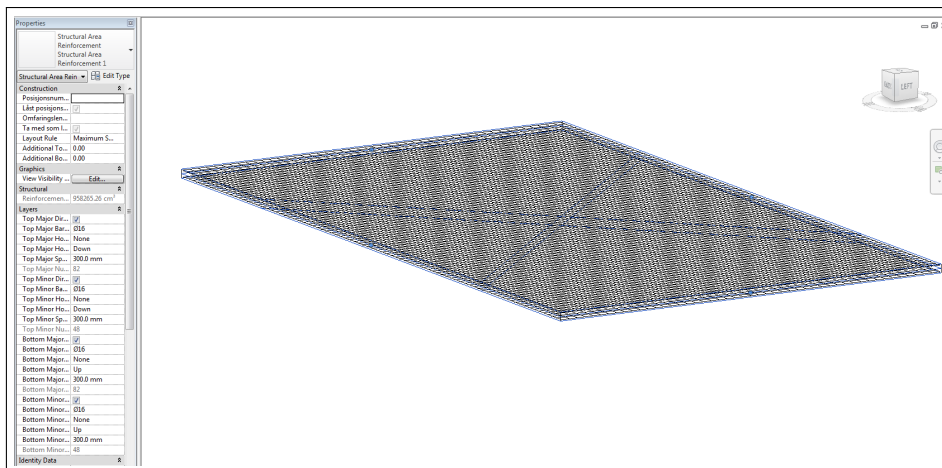


Figure 37: Area reinforcement of a floor

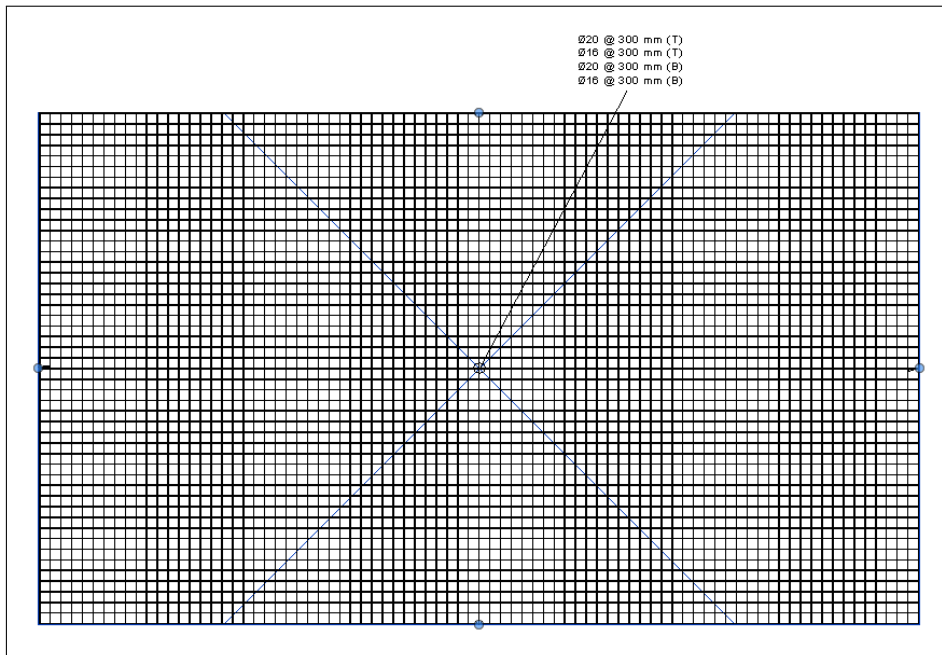


Figure 38: Area reinforcement tag

6.2 Revit reinforcement extension

The Revit reinforcement extension gives the user the opportunity to reinforce more than only floors, walls and foundation slabs. For the objects that are able to be reinforced with the area reinforcement tool, the extension provides at least the same functionality as the area reinforcement tool. An example of this tool is shown in figure 39, where a beam has been selected for reinforcement.

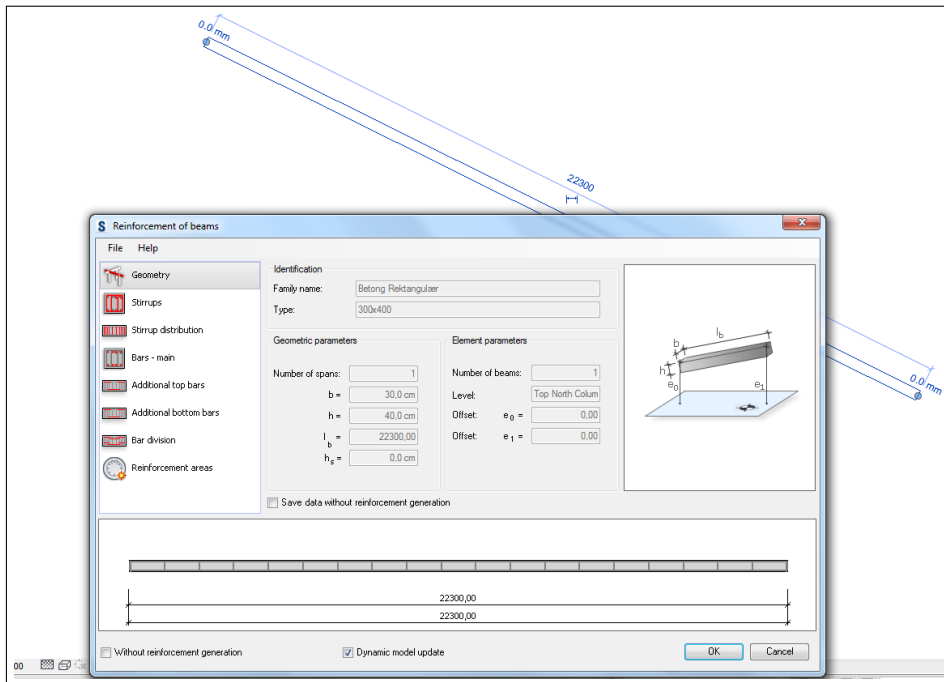


Figure 39: Revit reinforcement extension, beam

A lot of options, explained with figures, are available for quick establishment of rebars. The user is able to enter this menu again and make changes to the reinforcement.

6.3 The rebar tool

In bridge design and especially when dealing with cast in-place concrete, the geometry is most often non-standard and the rebar tool is by far the most valuable of the reinforcement tools. Thus, a major focus of this thesis will be on the functionality of this tool. Figure 40 shows the panels provided after selecting the rebar tool, where the geometry of the selected rebar shape and the spacing between the rebars are chosen. Rules for the orientation and the spacing of the rebars are easily modified through the Rebar Set menu.

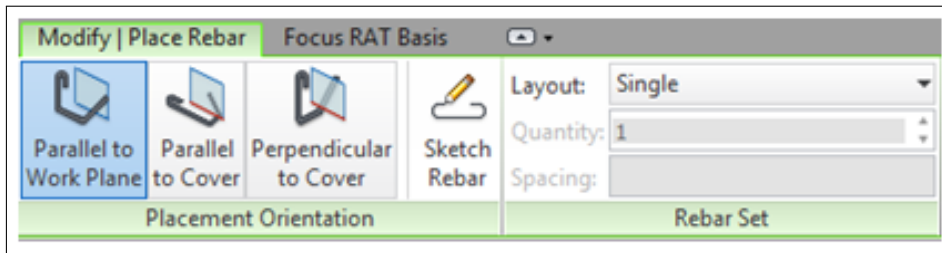


Figure 40: Rebar options

To place rebars in an object, the user has to create a section that cuts through the object in which the rebars should be inserted. The plane the section in which the rebars were created defines represents the work plane for the rebars inserted while in that section. The rebars can be inserted parallel to that work plane, parallel to the cover, or perpendicular to the cover (again, see figure 40). Several sections in different directions and positions are often needed in order to reinforce an object, and the user needs to be careful where the sections are placed related to rebars already placed in order to see them in that section.

6.4 Reinforcement of the substructure

The substructure of the bridge is not very geometrically challenging, and the rebars and functionality offered by the rebar tool were sufficient for modeling the rebars of the substructure. Before placing rebars, the user can move the rebars to be inserted around to get a preview of where they will be placed when clicking them out in the model window. The rebars will snap to different locations in the concrete object as the user moves them around. The correct amount and spacing between the rebars are specified through the Rebar Set Menu, and the direction of the spacing is determined by the orientation and shape of the rebar originally placed (40). The extents of the rebars and the rebar sets can be customized in the model window after creation with the use of shape handles, (blue triangles in figure 41) on top of the basic tools available for moving and altering an object (move, drag, rotate or altering of dimensions in the properties palette).

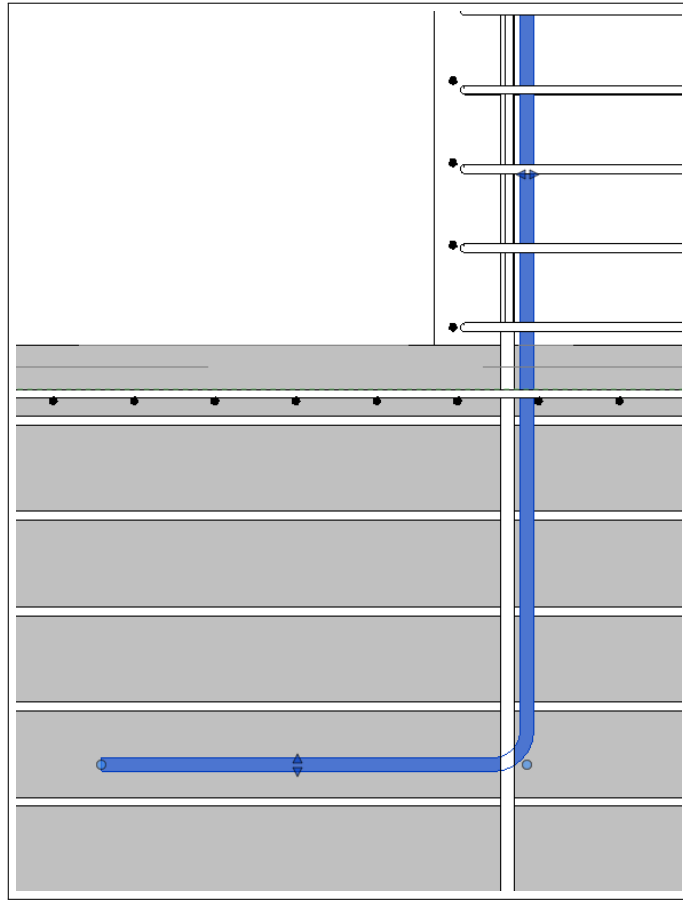


Figure 41: Rebar with shape handles

With the diameters and lengths of the rebars shown properly, the user is able to effectively move the rebars around and fit them next to other rebars appropriately. When rebars are inserted using one view, those rebars are also visible in the other views given the view range spans the area where the rebars are situated. The user also has the possibility of changing the position, length, spacing etc. of the rebars from other views, where the need for changes might be more apparent. If the rebars are selected in a view before switching to another view, the rebars are still displayed as selected in the second view.

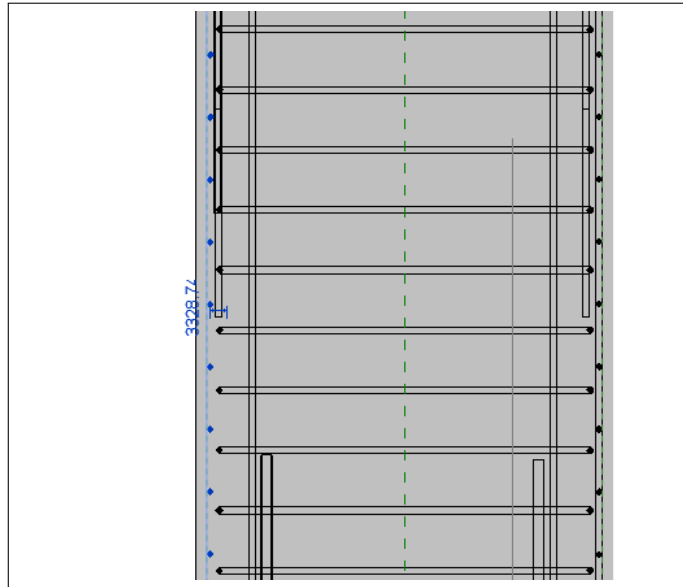


Figure 42: Rebars, elevation view

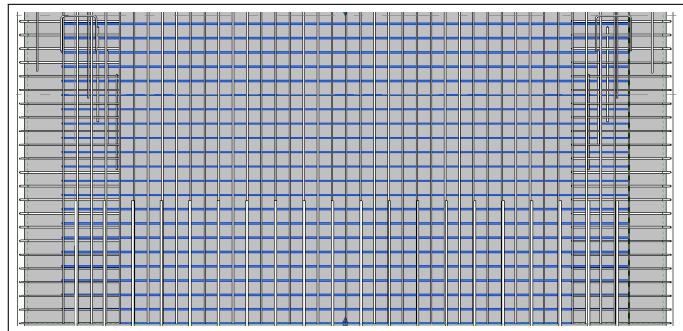


Figure 43: Rebars, front view

The rebars are also included in the 3D view, where the user can zoom in and inspect the very details of the reinforcement to verify the correct position of every bar.

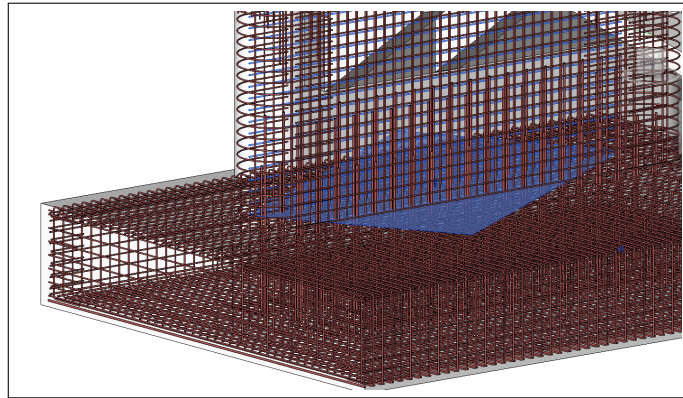


Figure 44: Rebars, 3D view

This is very useful, not only to spot errors that would be difficult to discover by looking at 2D-drawings; a 3D view of the rebar provides a good overview, which makes the people involved in the reinforcement work quickly get an idea of the reinforcement placement.

Rebars bent in one plane are easily modeled with the rebar tool. The only real issue with the reinforcement of the substructure was the rebar sets that needed to curve. The rebar anchored in the foundation slabs and going up into the columns, following the curvature of the columns were such rebar sets (Numbers K24328 and K24329 in figure 45).

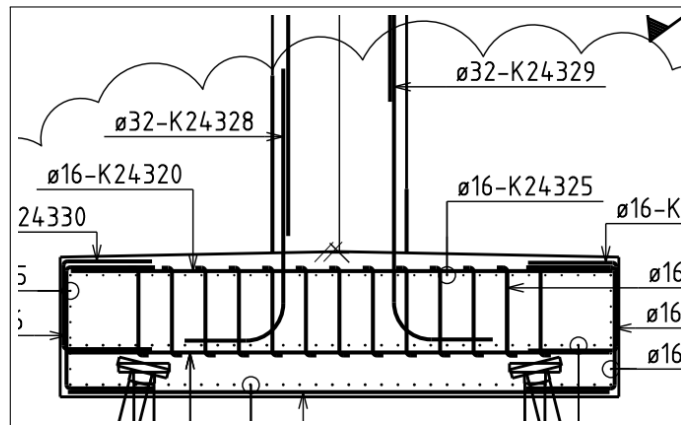


Figure 45: Rebars anchored in the foundation

These rebar could not be modeled with the use of the Rebar Tool and the Rebar Set Menu, as the spacing cannot follow a curve. Revit has a tool called “Array Group” which is suitable for this operation. By creating a bar at the right position, the user can then click the “Array Group” tool, choose a center of rotation around which rebar are to be placed. Then the user specifies the

span of the rebar set and the number of rebars in the group, creating the appropriate distance between the rebars. Figure 46 shows the array group of rebars from a top view of the column.

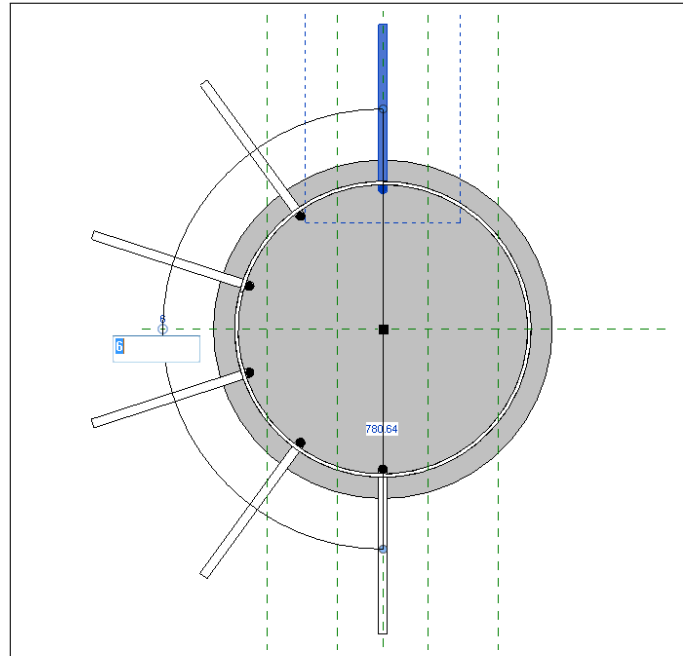


Figure 46: Rebars following the shape of the column

The number of rebars as well as the span range can be modified at any time. Each rebar in the rebar group can also be modified separately. Some customization is needed in order to get the right spacing between the rebars, as the spacing depends on the span range and number of rebars. The process would have been made easier by allowing the user to select the spacing between the objects in the array group, which at this time has to be determined through extra calculations.

6.4.1 Cover Distance

In Revit, the rebar cover (the distance from the edges of the concrete elements that defines a portion in which there should be no rebar) is defined in the concrete object itself, and the rebar cover area will be outlined with a green dashed line once a rebar object is selected, or a rebar object is to be created. Upon creation, the rebar objects snap to the dashed line and cannot be placed in a way resulting in a violation of the rebar cover distance. However, when created, the user is able to move the rebars around regardless of the rebar cover, yet the objects still snap to the dashed line for the user's convenience. One thing to note about the rebar cover distance is that the rebar objects in Revit

do not include the ribs, thus only the nominal diameter defines the rebar's extents. In Norway, the rebars are named after their nominal diameter, yet the real extent of the rebar is taken into consideration when inserting rebars. Figure 47 shows the nominal diameter and the full diameter including the ribs. The x in $\text{Ø}^k\text{x}$ represents the nominal diameter, and the number below is the real extent of the rebar.

Kamstål	Ø ^k 8	Ø ^k 10	Ø ^k 12	Ø ^k 16	Ø ^k 20	Ø ^k 25	Ø ^k 32
Byggemål (mm)	10	12	15	20	25	30	40

Tabell 5.3 - Byggemål for kamstål

Figure 47: Nominal diameter and real extents of rebars

When inserting rebars snapped to the rebar cover, they will be placed with a distance according to the nominal diameter, in practice resulting in a violation of the rebar cover distance. In figure 48 a rebar with a nominal diameter of 16mm is snapped to the rebar cover, which is set to be 75mm. Revit calculates the placement of the center of the rebar to be 83mm ($75\text{mm} + \frac{16\text{mm}}{2}$) from the edge of the concrete object, when it in fact should be 85mm ($75\text{mm} + \frac{20\text{mm}}{2}$).

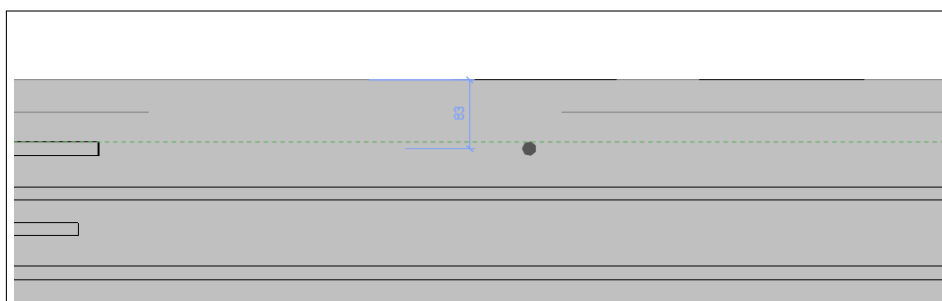


Figure 48: False rebar cover distance

The user is able to manually change the distance of the rebars after insertion in the model, but this is cumbersome. The rebar cover distance can only be specified to certain preset values in the properties palette (every 5mm ranging from 10-100mm), thus one is not able to specify these values accordingly for the concrete object. Also, the rebar cover distance needs to be different for a rebar with a nominal diameter of 16 and a rebar with a nominal diameter of 20. It is possible to edit the diameter of the rebar objects in order to represent the correct real extent in the model. However, by doing this, the calculation of the amount of rebar will be false. Revit keeps track of each rebar in the

model, and the user is able to quickly establish a sheet of the material usage, reinforcement area of the bars etc., which is a really useful tool and renders the tedious manual calculation obsolete. If the rebar area is not represented correctly, the calculations will not be correct.

6.5 Rebar Drawings

Even though Revit has the rebar included in the model, and the fact that the rebar can be inspected in both 2D and 3D views, rebar drawings are still useful when going into the details of the reinforcement work. Rebar drawings in Revit are made in 2D views, usually in sections created for that specific purpose. When in the section, the user makes use of the tag tool and simply clicks the rebars that should be tagged. In addition to the tags, Revit has several detail components and symbols which need to be used in the drawings. Regions of reinforcement can be represented by detail regions displayed in chosen patterns. Text can also be added if needed. Rebar drawings are made in a specific way which people are familiar with, thus the rebar drawings made in Revit should aim to follow the same style of annotation. However, since Revit has all the rebars included in the model, and the rebars are actual objects and not only lines on a sheet, one should also be aware of differences and look for opportunities to represent the drawings in a better way. In figure 49, a typical rebar drawing is presented. This drawing shows the rebars in the pier at the low end of the bridge.

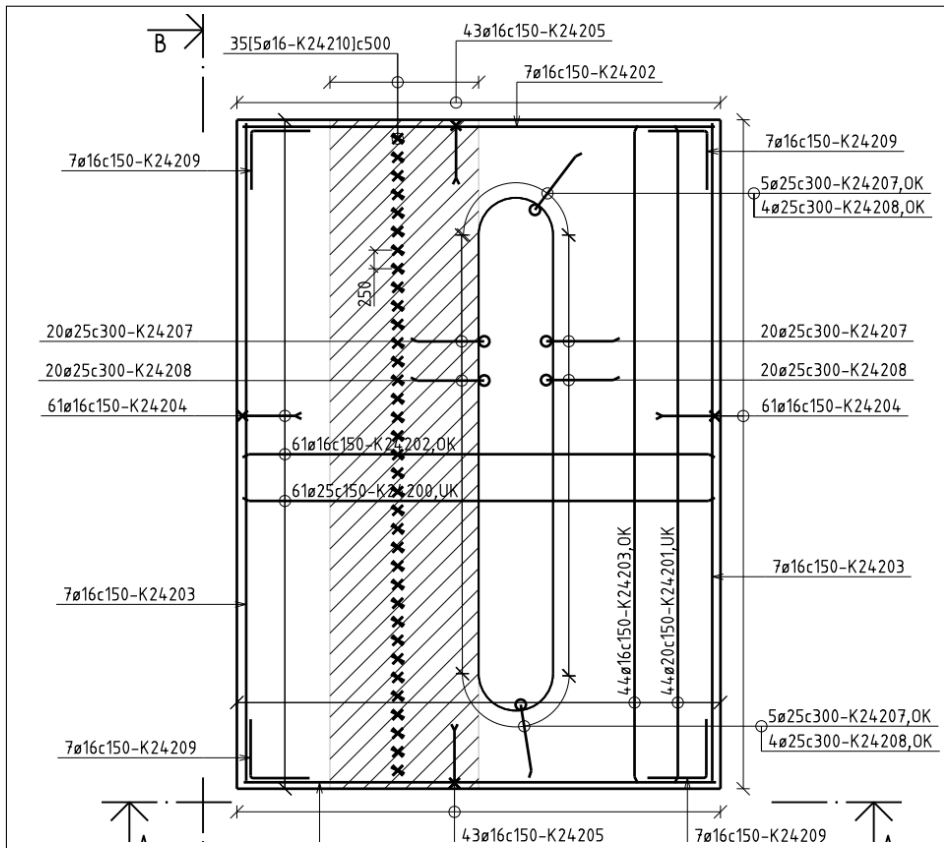


Figure 49: The original rebar drawing

The drawing is as clean as possible, usually only showing single rebars in the rebar sets. The extents of the rebar sets are indicated by lines, and the amount of rebars in each rebar set is shown connected to the rebars that are displayed in the drawing. The region consisting of diagonal lines represents an area with five rebar sets going into the plane downwards through the foundation.

All the rebars created are included in Revit, which means that the same section as shown in figure 49 will include an abundance of rebars, making it hard to get an idea of where each rebar is situated. Also, lines showing which rebars the rebar tags are referring to will virtually be unspottable. Figure 50 shows the section in Revit corresponding to the drawing in figure 49.

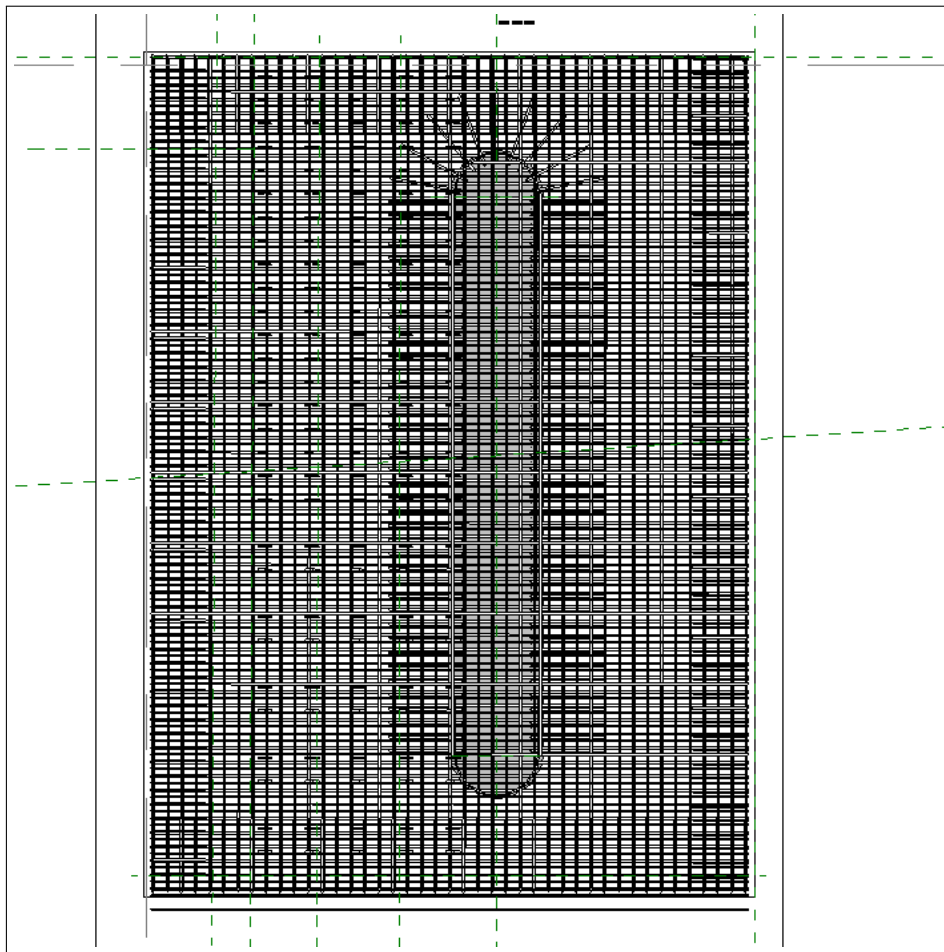


Figure 50: Top view of the pier in Revit

Evidently, in order to create a sensible rebar drawing, one has to make some adjustments to the section. Firstly, the rebar tags need to be placed at the rebars in the section. Secondly, it is desirable to hide the rebars tagged from the view, only showing their extent with lines. This cannot be done with the “hide element” command, the normal tool used for this operation, as the rebar tag will be hidden along with the object. Focus Software has developed several tools in their “Revit Advanced Tools” extension to Revit, which make the reinforcement work more efficient. One of those tools is the “Show/Hide Rebar” command, which hides the rebar in the view by changing the visibility settings of the rebar without explicitly hiding the rebar using the “hide element” command. Thus, the rebar tag remains in the view, solving the problem. The tags do not show the extent of the rebar sets they annotate, and the user needs to make use of rebar detail components. There are both tags and detail components included in Revit, and additional objects can be downloaded from Autodesk’s webpage. Focus Software has also made its own tags and detail components suitable for the construction business in Norway,

and these are the objects used in this thesis. After some cleanup work, the section provides a better overview of the reinforcement of the pier.

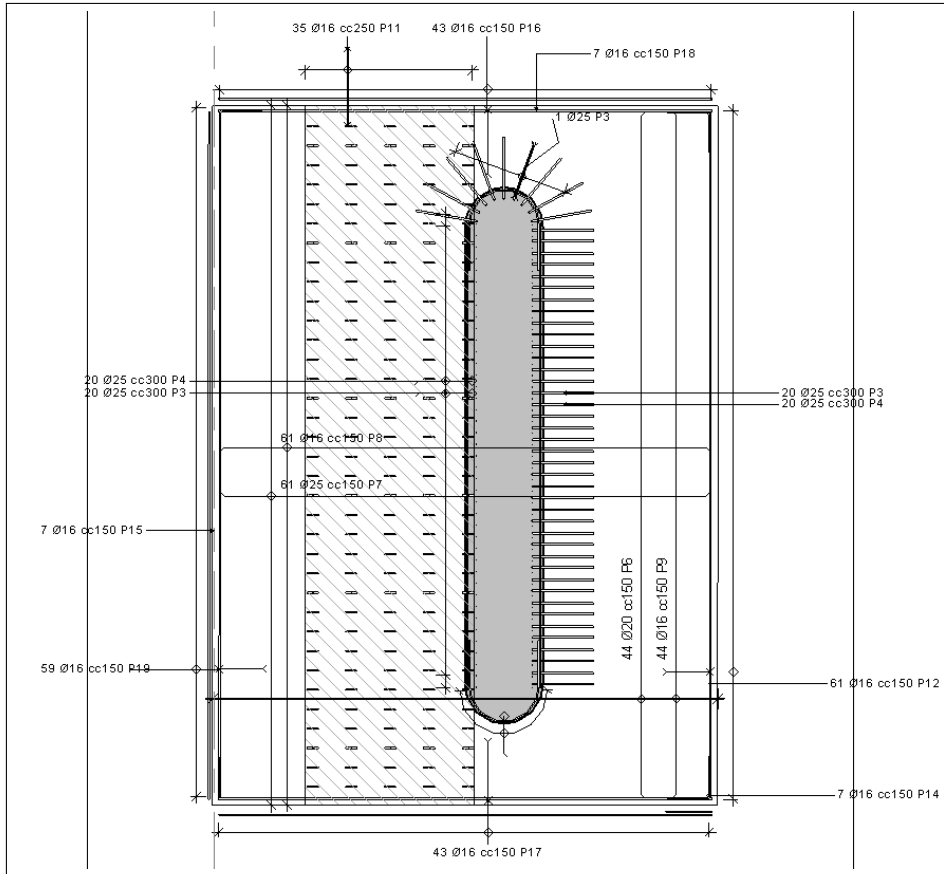


Figure 51: Top view of the pier in Revit, after cleanup and annotation

There are still some adjustments that could be made to this view; the rebars going downwards from the column anchored in the foundation are all displayed in the view on the right hand side of the column. These could be displayed as done in figure ??, and on the left hand side of the column. However, the rebars are already created in Revit, and the procedure of representing them this way only provides extra work hiding them in the view and inserting an additional detail component. When the rebars do not coincide with other objects in the view one might as well keep them as long as the correct tag is placed. There are a couple of other things to note about this view. The rebars anchored in the foundation, which are situated at the ends of the column, following the curvature, could not be represented with the rebar tool alone (as described in 6.4). The rebar set had to be created using the “Array Group” tool, which has a drawback with regard to the rebar drawing. When attempting to tag the rebar set, the rebars were treated as separate. As a work around, one has the possibility of manually inserting a text annotating the rebar set properly. The

rebars are included in the overall schedule of rebars, such that calculations will be correct. Additionally, they have the same schedule mark/position number. As a result, the only part of the model affected by this work around is this very view, as the text will not update automatically if changes are made to the rebar set. Nevertheless, the best case scenario would be that the rebar tool could successfully represent rebar sets following a specific curve. Furthermore, the array group should be able to be tagged as a whole. The other thing realized through tagging the rebars was the fact that several rebar sets could not be tagged together. The region represented by the diagonal lines includes five identical rebar sets. In the original rebar drawing (49), these are combined and shown as 35 [5ø16-24210]c500. A solution is to tag all of the rebar sets individually; however there should be a way to include all of the rebar sets in one tag. Additionally, the spacing in Revit (51), where the spacing listed is the one between each rebar in the rebar set, differs from the one displayed in the original drawing.

6.6 Rebar documentation

When creating rebar, the amounts, schedule mark, lengths etc. need to be included in a list in order for the manufacturer to know what to produce and how to label the rebars manufactured. This is very quickly done in Revit. All the rebars used are stored in the database, and when creating a list specified to show information about rebars, the list will automatically include all the rebars in the model. Afterwards, the user simply needs to add the appropriate fields to be shown in the list (bar diameter, bar length, total volume etc.). The user is able to specify rules by which the list is sorted. Focus Software has developed a function which automatically assigns schedule marks to rebars, relieving the user of the cumbersome process of manually assigning schedule marks.

Rebar Schedule							
Family and T	Schedule Ma	Count	Bar Length	Bar Diameter	Material	Shape	Reinforcement Volume
Rebar Ba	6	14		32	Kamstål B	12	
Rebar Ba	P1	1	8611.91	25	Kamstål B	00	29591.53 cm ³
Rebar Ba	P2	3	8850	16	Kamstål B	00	78293.52 cm ³
Rebar Ba	P3	2	3298.13	25	Kamstål B	12	32379.32 cm ³
Rebar Ba	P4	2	2635.45	25	Kamstål B	12	25873.46 cm ³
Rebar Ba	P5	1	8850	20	Kamstål B	aci-Standard - 0 - 0	122333.62 cm ³
Rebar Ba	P6	1	6350	25	Kamstål B	aci-Standard - 0 - 0	190139.99 cm ³
Rebar Ba	P7	1	6350	16	Kamstål B	aci-Standard - 0 - 0	77881.34 cm ³
Rebar Ba	P8	1	1248.94	16	Kamstål B	Rebar Shape 6	8789.01 cm ³
Rebar Ba	P9	1	1249.34	16	Kamstål B	Rebar Shape 6	8791.83 cm ³
Rebar Ba	P10	3	1249.68	16	Kamstål B	Rebar Shape 6	8794.18 cm ³
Rebar Ba	P11	1	2183.95	16	Kamstål B	21	26785.67 cm ³
Rebar Ba	P12	1	5975.16	16	Kamstål B	00	27631.65 cm ³
Rebar Ba	P13	1	5976.36	16	Kamstål B	00	27637.23 cm ³
Rebar Ba	P14	1	3283.99	16	Kamstål B	00	27071.67 cm ³
Rebar Ba	P15	1	3293.74	16	Kamstål B	00	27152.08 cm ³
Rebar Ba	P16	2	2598.01	16	Kamstål B	13	12536.66 cm ³
Rebar Ba	P17	1	1050.12	16	Kamstål B	11	1477.97 cm ³
Rebar Ba	P18	1	1042.81	25	Kamstål B	11	3583.22 cm ³
Rebar Ba	P19	1	1063.85	16	Kamstål B	11	1497.29 cm ³
Rebar Ba	P20	1	2747.29	16	Kamstål B	21	23752.13 cm ³
Rebar Ba	P21	1	2637.04	16	Kamstål B	21	22798.98 cm ³
Rebar Ba	P22	2	6350	16	Kamstål B	00	8937.20 cm ³
Rebar Ba	P23	1	1753.51	16	Kamstål B	12	2115.38 cm ³
Rebar Ba	P24	1	1767.77	16	Kamstål B	12	2132.59 cm ³
Rebar Ba	P25	1	5831.01	16	Kamstål B	00	7034.36 cm ³
Rebar Ba	P26	2	1074.64	16	Kamstål B	21	2592.83 cm ³
Rebar Ba	P27	7	2839.67	16	Kamstål B	21	570.95 cm ³
Rebar Ba	P28	1	2837.42	16	Kamstål B	21	570.50 cm ³
Rebar Ba	P29	2	5754	32	Kamstål B	00	4627.64 cm ³
Rebar Ba	P30	4	2592.08	20	Kamstål B	21	814.33 cm ³
Rebar Ba	P31	1	5754	20	Kamstål B	00	1807.67 cm ³
Rebar Ba	P32	4	2937.08	20	Kamstål B	21	922.71 cm ³
Rebar Ba	P33	1	211203	12	Kamstål B	77	23886.50 cm ³
Rebar Ba	P34	3	1389.67	16	Kamstål B	21	279.41 cm ³
Rebar Ba	P35	3	1403.67	16	Kamstål B	21	282.23 cm ³
Rebar Ba	P36	6	1010.67	16	Kamstål B	21	203.21 cm ³
Rebar Ba	P37	6	992.08	20	Kamstål B	21	311.67 cm ³
Rebar Ba	P38	1	2162.17	16	Kamstål B	21	25649.08 cm ³
Rebar Ba	P39	1	4131.89	20	Kamstål B	12	1298.07 cm ³
Rebar Ba	P40	8	4764.12	32	Kamstål B	12	3831.54 cm ³
Rebar Ba	P41	1	4759.91	32	Kamstål B	12	3828.15 cm ³
Rebar Ba	P42	1	6200	20	Kamstål B	00	13634.51 cm ³
Rebar Ba	P43	1	672.11	16	Kamstål B	21	4594.61 cm ³
Rebar Ba	P44	1	1559.45	16	Kamstål B	Rebar Shape 7	4076.09 cm ³
Rebar Ba	P45	1	1326.43	16	Kamstål B	11	46938.37 cm ³
Rebar Ba	P46	1	3025.39	16	Kamstål B	25	8516.08 cm ³
Rebar Ba	P47	1	3647.2	16	Kamstål B	21	23466.04 cm ³
Rebar Ba	P48	1	3646.9	16	Kamstål B	21	733.25 cm ³

Figure 52: Rebar list sorted by schedule mark

The top row shows a problem related to the rebars created as array groups in order to represent rebar sets (see section 6.4). The groups are not included correctly in the rebar list, nor are they assigned with a correct schedule mark by Focus Software's schedule mark function. In the list in figure 52, all the rebars in the array group are included, with the right bar diameter and shape. However, the bar length and volume fields are blank. The reason was discovered to be that there were two array groups, both having the same schedule mark but different lengths of the rebars. When assigning the rebars in one of the array groups with a new schedule mark, the rebars were displayed correctly in the rebar list.

Rebar Schedule							
Family and T	Schedule Ma	Count	Bar Length	Bar Diameter	Material	Shape	Reinforcement Volume
Rebar Ba	6	4	4764.12	32	Kamstål B	12	3831.54 cm ³
Rebar Ba	7	10	3039.67	32	Kamstål B	12	2444.65 cm ³
Rebar Ba	P1	1	8611.91	25	Kamstål B	00	29591.53 cm ³
Rebar Ba	P2	3	8850	16	Kamstål B	00	78293.52 cm ³
Rebar Ba	P3	2	3298.13	25	Kamstål B	12	32379.32 cm ³
Rebar Ba	P4	2	2635.45	25	Kamstål B	12	25873.46 cm ³
Rebar Ba	P5	1	8850	20	Kamstål B	aci-Standard - 0 - 0	122333.62 cm ³
Rebar Ba	P6	1	6350	25	Kamstål B	aci-Standard - 0 - 0	190139.99 cm ³
Rebar Ba	P7	1	6350	16	Kamstål B	aci-Standard - 0 - 0	77881.34 cm ³
Rebar Ba	P8	1	1248.94	16	Kamstål B	Rebar Shape 6	8789.01 cm ³
Rebar Ba	P9	1	1249.34	16	Kamstål B	Rebar Shape 6	8791.83 cm ³
Rebar Ba	P10	3	1249.68	16	Kamstål B	Rebar Shape 6	8794.18 cm ³
Rebar Ba	P11	1	2183.95	16	Kamstål B	21	26785.67 cm ³
Rebar Ba	P12	1	5975.16	16	Kamstål B	00	27631.65 cm ³
Rebar Ba	P13	1	5976.36	16	Kamstål B	00	27637.23 cm ³
Rebar Ba	P14	1	3283.99	16	Kamstål B	00	27071.67 cm ³
Rebar Ba	P15	1	3293.74	16	Kamstål B	00	27152.08 cm ³
Rebar Ba	P16	2	2598.01	16	Kamstål B	13	12536.66 cm ³
Rebar Ba	P17	1	1050.12	16	Kamstål B	11	1477.97 cm ³
Rebar Ba	P18	1	1042.81	25	Kamstål B	11	3583.22 cm ³
Rebar Ba	P19	1	1063.85	16	Kamstål B	11	1497.29 cm ³
Rebar Ba	P20	1	2747.29	16	Kamstål B	21	23752.13 cm ³
Rebar Ba	P21	1	2637.04	16	Kamstål B	21	22798.98 cm ³
Rebar Ba	P22	2	6350	16	Kamstål B	00	8937.20 cm ³
Rebar Ba	P23	1	1753.51	16	Kamstål B	12	2115.38 cm ³

Figure 53: Array group rebars displayed correctly in the Rebar list

The solution to the problem was simple, however, if the user frequently needs to resort to array groups instead of using the tools already provided for rebar by Revit, the result is a lot of additional work in order to both represent the rebars and keep track of the schedule marks.

In addition to this list, Focus Software has developed a tool which establishes a rebar bending schedule showing information about the rebars including geometry. The rebar bending schedule automatically gathers the information, and a simple click on the tool generates the whole schedule. If rebars are selected, only the selected rebars are included in the schedule. The rebar bending schedule shown in figure 54 included 60 different schedule marks, and was created within seconds. The reduction in the amount of work compared to traditional methods, where this would have to be done manually, is huge.



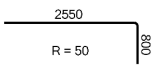
BØYELISTE			Prosjekt				Revisjon:	
Project Number					Jernlengde	12000	Utsendt: 02.05.2013	
Pos. nr.	Antall av lev. lengde	Antall stk.	Nærmere betegn. Anmerkninger	Kvalitet	Diam mm	Kapl. mm	Skisse Mål i mm ifølge NS 3766	Sum lm
P1	0	7		Kam stål B500 NC	25	8612		61
P2	0	132		Kam stål B500 NC	16	8850		1169
P3	0	40		Kam stål B500 NC	25	3298		132

Figure 54: Excerpt of a rebar bending schedule

6.7 Reinforcement of the bridge deck

A major problem with the bridge deck reinforcement is the fact that the path which a set of rebars follow cannot curve. Several rebars were supposed to be perpendicular to the centerline of the bridge with a fixed spacing along the centerline, thus curving along the centerline. Rebar created in a cross section perpendicular to the centerline at one location have the right orientation in that section, however when multiple rebars are created from that rebar profile through the Rebar Set Menu, the added rebars will be placed parallel to the original rebar, extending the rebar set in a straight line. Figure 55 shows this effect; the set of rebars selected was created in the section cutting the bridge at the left hand side, and does not curve with the bridge deck, but stretches out perpendicularly from the section.

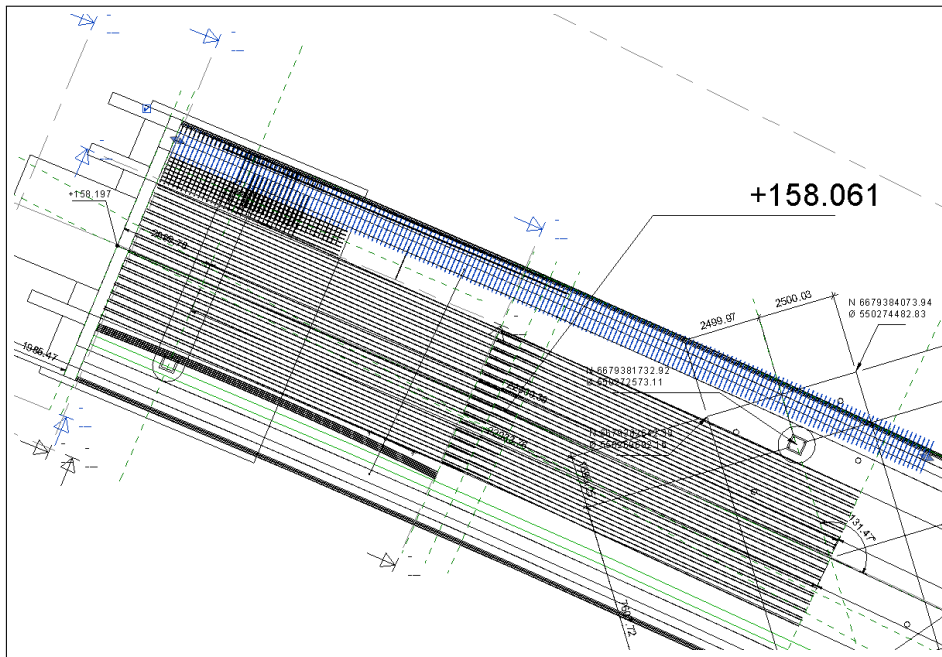


Figure 55: Rebar set does not curve with the bridge deck

This also affects the longitudinal reinforcement if it is created in a cross section of the bridge. The solution to this problem is, at the moment, a very pragmatic one; a rebar set can only span a portion of the bridge before a new rebar set with a slightly different orientation has to be placed. Although this is not desirable, it is the best solution given Revit's current functionality. Autodesk is continuously working with rebar improvements, and this issue is probably one that will be given attention in future releases of Revit. The longitudinal reinforcement can be created in a plan view, which enables the user to assign a curve to the rebars using the "sketch rebar" tool. The user is also able to assign a reference plane following the slope of the bridge as the work plane, such that the rebar is placed on that plane. The Rebar Set Menu cannot be used to assign spacing between the rebar in this case, because the added rebar will be placed with the spacing oriented vertically, not horizontally. In order to create the wanted number of rebars horizontally, one has to manually copy the bars. The "Array Group" tool is suitable for this operation. By creating a bar with the appropriate curvature, the user can then click the "Array Group" tool, specify the span of the rebar set and the number of rebars in the group. However, after inserting a segment of rebars using the "Array Group" tool, the program started having performance issues (not responding), rendering modeling almost impossible. Also, rebars in the array group are harder to customize once created compared to rebars created by the standard procedure. Rebars for this use are usually cut in lengths of 12000mm, and are not pre-bent in the case of a large radius (in this case 600m). The question

in this regard is if the representation of sets of 12000mm straight rebars is satisfactory. At the ends of each rebar set, there will be an inaccuracy because the next set will have a different orientation in the horizontal plane.

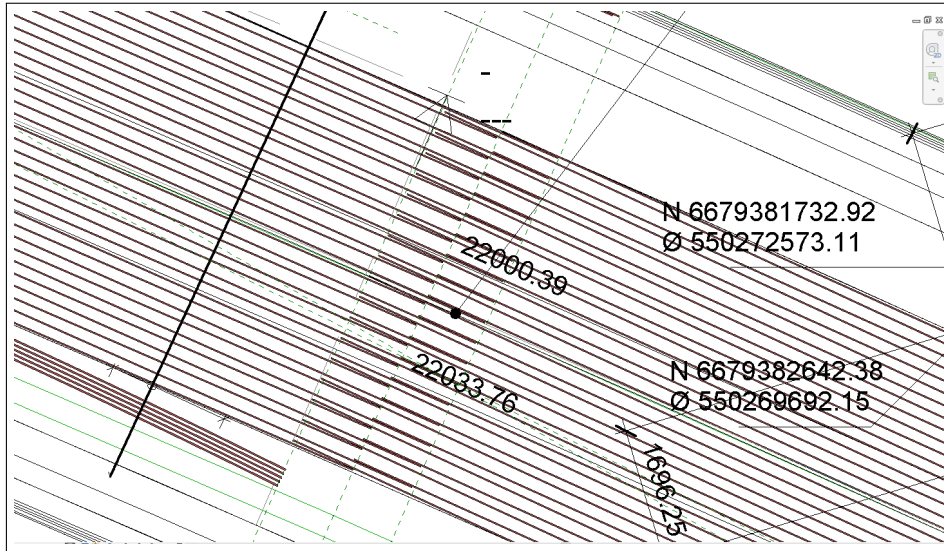


Figure 56: Inaccuracy at the ends of the rebar sets

An issue arose when trying to add rebar to the bridge deck; the rebar was not placed onto the work plane defined by the section created for the insertion of the rebar, but ended up at a different location seemingly without any connection to the section. In figure 57 the section and the added rebar are displayed. The section is indicated by the two arrows and the blue dashed line, and the rebar is the blue line in the bottom section of the picture (the rebar is hovered over with the mouse, which reveals the object name and type).

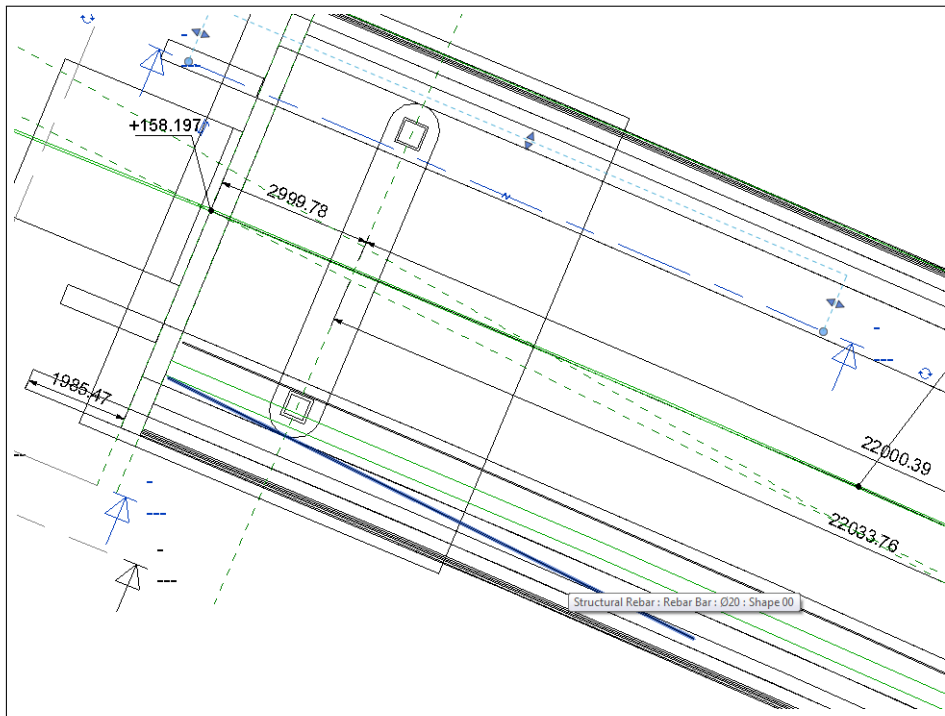


Figure 57: Section and rebar not coinciding

The solution was to create a reference plane where the rebar was supposed to be inserted and set that reference plane as the work plane before entering the section and placing the rebar.

6.8 Post-tensioning reinforcement

The creation of the PTR is particularly difficult. It curves along with the bridge deck as well as having different elevations along its length.

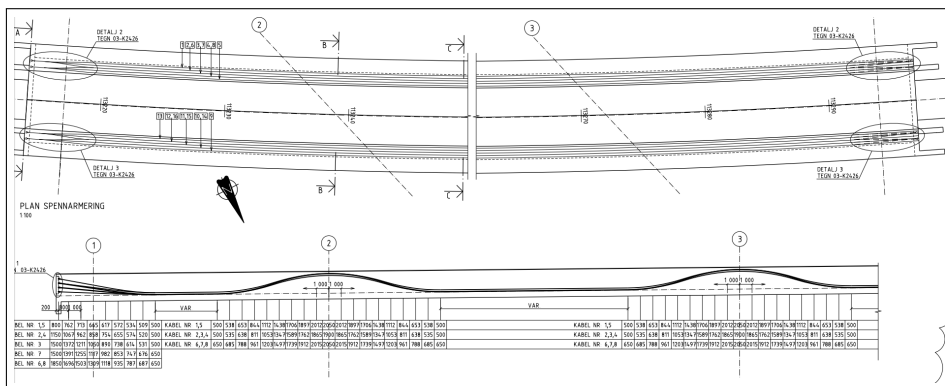


Figure 58: Overview of the PTR running along the length of the bridge

Standard rebar shapes are not applicable for this reinforcement, and tensioned reinforcement behaves differently and redistributes stresses and strains. The sketch tool does not work, because it is confined to a plane and has limitations determined by the section in which you draw the rebar, and there is no possibility to attribute a rebar curvature in two planes with this tool. Thus, other methods need to be considered. It is possible to create this kind of geometry using the "In-Place Mass" tool which is mentioned in 4.2.1. A portion of one of the PT tendons was modeled using this tool. Points were created along the length of the rebar with a spacing of 1000mm and given approximately the right elevation. For each point, both a reference plane and a section had to be created in order to add a circular profile to each point. The sections were created to view the specific point, and the corresponding reference planes were needed for the profiles to be placed on. This way one was able to create a path of circular profiles for an "In-Place Mass" to follow.

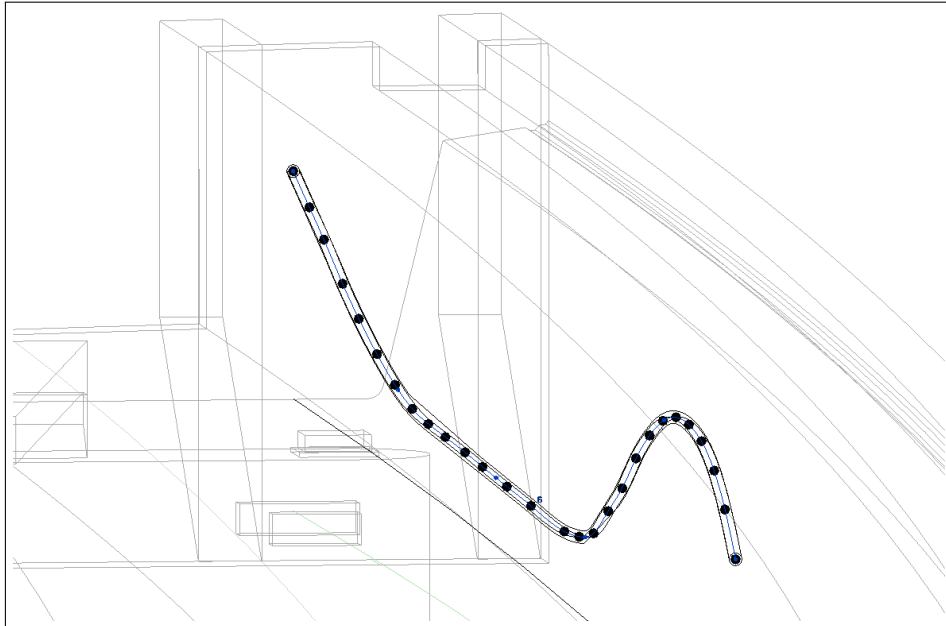


Figure 59: The reinforcement as an "In-Place Mass"

The "In-Place Mass" object displayed in figure 59 is not completely accurate. However, it is possible to attain the correct geometry once enough points are added at the exact positions. Each point is assigned a host plane on which they are placed, and the points can be assigned an offset from that plane after creation to control their elevation. By selecting a plane following the slope of the bridge, one is able to control the elevation profile of the object satisfactorily. Each point can also be selected and dragged to a position of the user's choice. Yet, the procedure is very cumbersome due to the fact that reference planes and sections are needed for each point, and that every point needs to

be adjusted to create the desired geometry. Once the reference planes and sections are placed in the model, they can be used for each of the post tensioning reinforcement objects since they follow the same curvature, which means they only need to be created once for all of the post tensioning reinforcement.

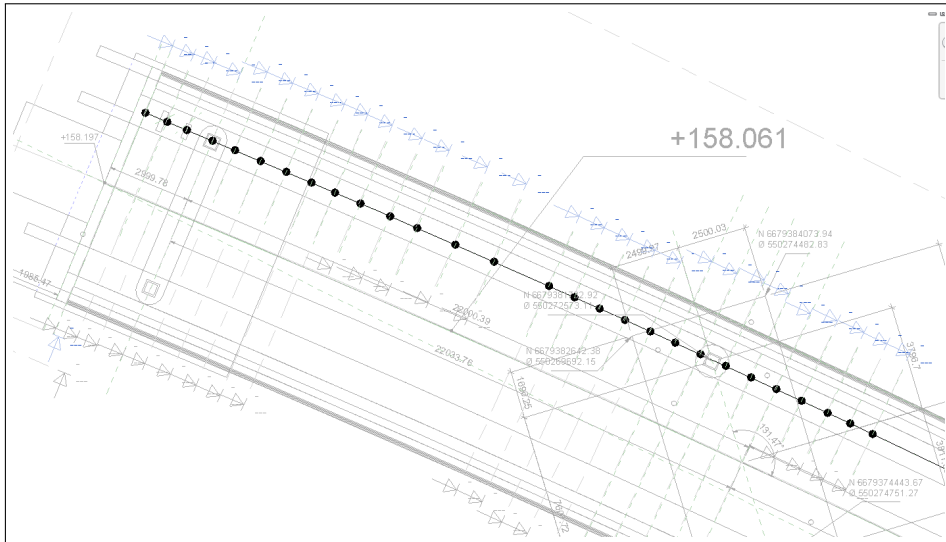


Figure 60: Points with reference planes and sections

There is no way of quickly changing the geometry of the object; if the object needs to be altered, each point affected needs to be altered as well. Furthermore, the profiles associated with each point are not attached to the points, and will have to be moved manually to reflect the change of position of the points. Also, to obtain a completely accurate object, the profiles created at each point need to be perpendicular to the direction of the path by which the object follows. Thus, the reference planes will need to be rotated slightly, which requires a lot of extra work due to the fact that new sections has to be created perpendicularly to the reference planes in order to rotate the reference planes. Figure 61 shows this inaccuracy for four points with their accompanying vertical circular profiles.

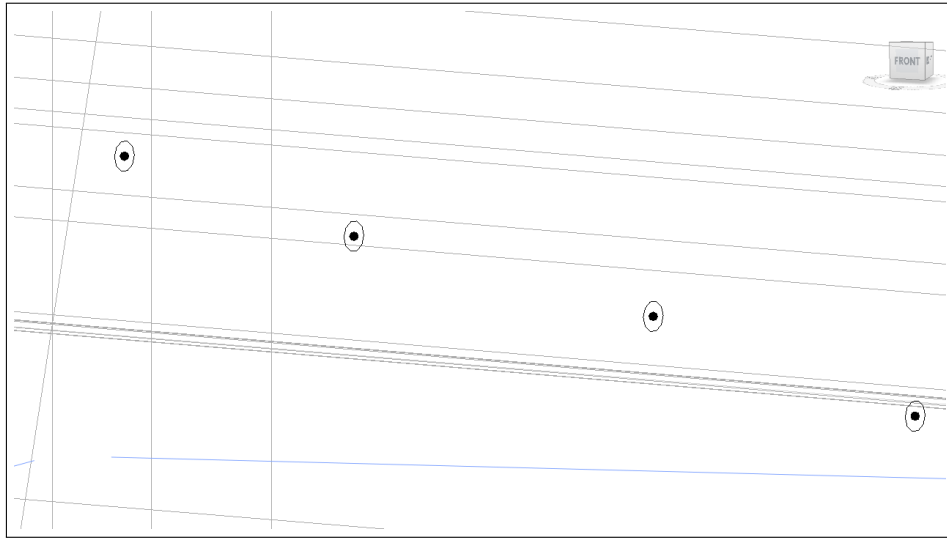


Figure 61: "In-Place Mass" points and profiles

It was concluded that this method was not feasible for the modeling of the PTR. However, there are modeling engineers who have worked with PTR in Revit, and they have managed to come up with families from which objects can be inserted [15]. These families are not yet in the standard Revit library, and require more than a moderate amount of skill to model. The PT tendons in the examples shown of these families are limited to one or two spans with a smooth curve from top to bottom, which require 3 and 5 points respectively. The PTR in the bridge modeled in this thesis has area where the reinforcement flattens out altogether before rising towards the columns, thus more points are needed in order to represent this correctly. Since the geometry of the PT tendons differs from bridge to bridge, making a family customizable to each reinforcement case is a difficult challenge. Sundt Construction modeled the PTR in Civil 3D (3.2), where geometry curving in several planes is more easily represented. Even though the objects are not parameterized to the same extent as in Revit, and does not hold the same interplay with Revit objects, this might be a good alternative.

7 Discussion and conclusion

7.1 BIM, Revit and Robot in bridge design

Through pilot projects, BIM has been proven an asset to the bridge design process. The ability to better visualize the project resulting in better communication between the parties is valuable. The automatic update of objects everywhere in the model, and the storage of material data easily extractable to

lists and schedules, renders several cumbersome manual operations obsolete.

The collaboration between other software and Revit works satisfactorily. Road and underlay models can be imported as aid for continued modeling in Revit; however, they need to be appropriate for BIM purposes (i.e. consist of continuous line segments). This thesis does not explicitly investigate the representation of the model created in Revit with other disciplines, however the export of Revit models to the .dwg file format for usage in for example Novapoint® Virtual Map™ or Autodesk® Navisworks™ (programs for 3D representation of the collaboration of different disciplines like structural, architectural and MEP) works well. Norconsult is using Revit files exported to .dwg in Novapoint Virtual Map, and Navisworks can even handle Revit files (.rvt) [16].

In terms of the modeling in Revit, there are still issues; non-standard geometry is hard to represent, work with, dimension and reinforce. These issues need to be remedied, especially if Revit is to be used for bridge design without aid from other programs. Companies that use BIM extensively in their bridge design tend to not only model in one program, but utilize the different softwares' advantages. Sundt Construction uses Civil 3D for the modeling of the bridge superstructure, while the substructure along with different documentation are covered in Revit.

The use of Robot was not studied extensively in this thesis; however, it seems that non-standard geometry also makes the incorporation of Robot difficult. If the interaction between Revit and Robot was investigated further, solutions might have been found, and a skilled user may be able to perform analysis of bridges with non-standard geometry. Nonetheless, there are complications related to this process. Not being able to transfer the bridge model made in Revit for structural analysis in Robot effectively is a serious drawback. If the solution is to resort to other programs, extra time will need to be spent creating a new model for structural analysis in those programs. Furthermore, one will not gain the ability to automatically alter the Revit model based on proposed changes by Robot after the structural analysis.

7.2 Differences between traditional methods and BIM

A consequence of employing BIM is that one cannot manipulate the geometry in the drawings in the same way one would do in traditional bridge design. A good example of this is the elevation view of the bridge. In traditional bridge design the drawing would display the bridge as having the centerline stretched out like a straight line in the horizontal plane, yet add the length of the bridge as it having a curve. There is no possible way of doing the same when utilizing BIM since the model consists of actual objects, and not just multiple separate drawings of the same structure. In figures 62 and 63 a point elevation is included on the centerline at the end of the wing walls of

the bridge. The point elevations are in fact both exactly at the edge of the wing walls when looking perpendicularly at the bridge at that point, but since the bridge curves and the centerline lies beyond the wing wall it looks like the point lies to the left of the wing wall in the BIM.

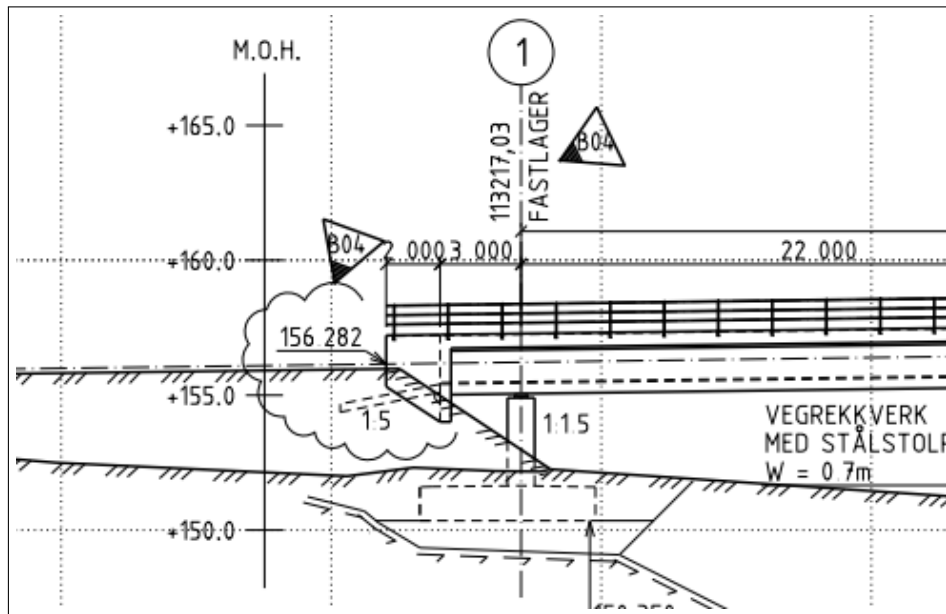


Figure 62: The end of the wing wall in the drawing

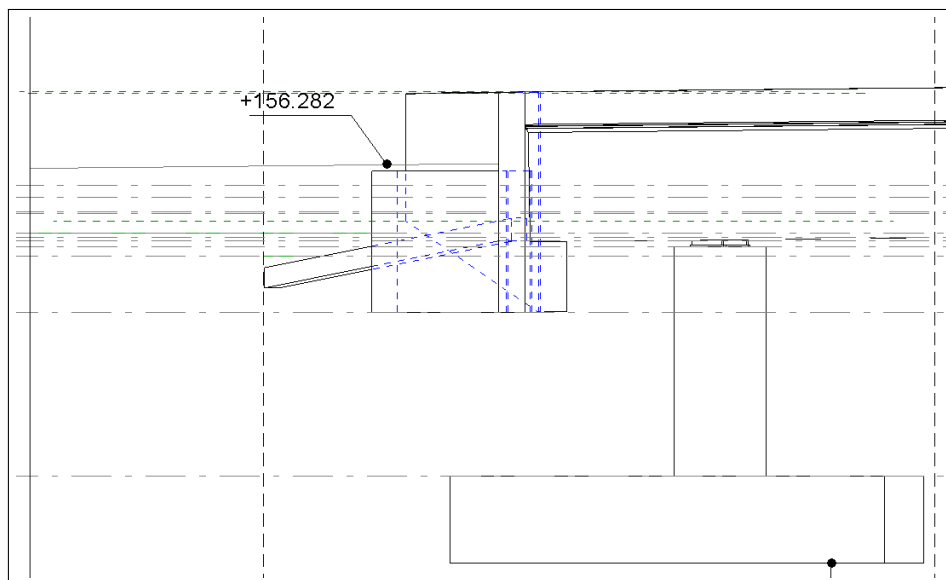


Figure 63: The end of the wing wall in the BIM.

This problem could be solved if Revit included functionality for curved

sections. That way the user would be able to add a section with the same curvature as the bridge with an offset and thus attain the same elevation view as in the drawing. The question in this regard is whether or not it is necessary; BIM brings new challenges to the table, but also possible improvements and opportunities to think differently. In this particular problem one could agree that it would be useful to be able to display the point elevation exactly at the end of the wing wall, and therefore the traditional representation has some positives. However, all of the information is available in the model! It is just a matter of how it should be presented. For instance, the point elevation might just as well be added in the plan view, where the length of the centerline between specified points could also be added. This would leave the correct horizontal length of the bridge to be displayed in the elevation view.

7.3 Skill Level

The skill level of the user is of great importance when performing BIM; there may be several ways to do a certain task, or there may be none. The problem is that without the proper skill the user does not know whether or not there is a way to do a specific task, let alone how to do the task. Sometimes, the operation by which a task is completed is not intuitive, and work-arounds need to be put to use. The process of discovering these operations (or not discovering them) may take several hours; however, once the user knows how they are performed they are completed in the matter of seconds. An example is the measuring of the arc length of a specific portion of the centerline of the bridge. To measure an arc length the user needs to specify the arc which is to be measured, before selecting two intersecting lines as boundaries. It was not possible to make use of the centerline itself when attempting to perform the operation. During the process of figuring out how to measure the arc length, there are numerous possible issues to consider. Following are some examples of possible reasons why the line was unable to be measured:

- The line was an imported dwg-file.
- The line was not properly shaped for the use of the arc length tool (i.e. that its radius varied).
- The intersecting lines or objects might not have been appropriate for the arc length tool.
- The elevation change throughout the centerline might have caused issues for the tool.

The next step in the investigation was the creation of a model line (a line that is visible in all views, and assigned to a given plane) as a projection of the centerline on the horizontal plane. This did not provide the wanted

results. Finally, a model line was created in the horizontal plane by manually typing in the radius of the arc and adjusting it to fit the centerline of the bridge, or rather the projection of the centerline. This line would let itself be measured by the arc length tool, thus most probable cause of the problem was the centerline itself not being a proper arc. However, the centerline was able to be clicked while having the arc length tool selected, which in theory should only be possible for arcs.

7.4 Reinforcement

The reinforcement of standard objects that are not curved works really well in Revit; rebars are quickly established, and the rebar functions Revit holds are sufficient. However, there is a need to improve the flexibility of the rebar tools for objects with curved geometry. Several operations attempted in this thesis were rendered impossible or cumbersome as an effect of the lack of functions provided by the tools.

- Curved rebar sets: rebars created through the tools provided by Revit can be curved in one plane. However, when creating a rebar set based on a rebar, the spacing between the rebars can only have an orientation directly outwards from the plane in which the original rebar was placed. This caused issues when creating the reinforcement for the columns (6.4) and the bridge deck (6.7). The solution was to either split up the rebar sets, creating several straight segments to represent a curve, or to represent the rebar sets with array groups. Neither of these options is desirable, as splitting up the rebar sets results in wrong rebar placement, and the array groups are harder to work with and makes the model slow to work with.
- Post-tensioning reinforcement: there are no PTR families in Revit, and it is difficult to model new families. Modeling the PTR through the "In-Place Mass" tool is not feasible. Importing the PTR geometry from Civil 3D is an alternative.

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