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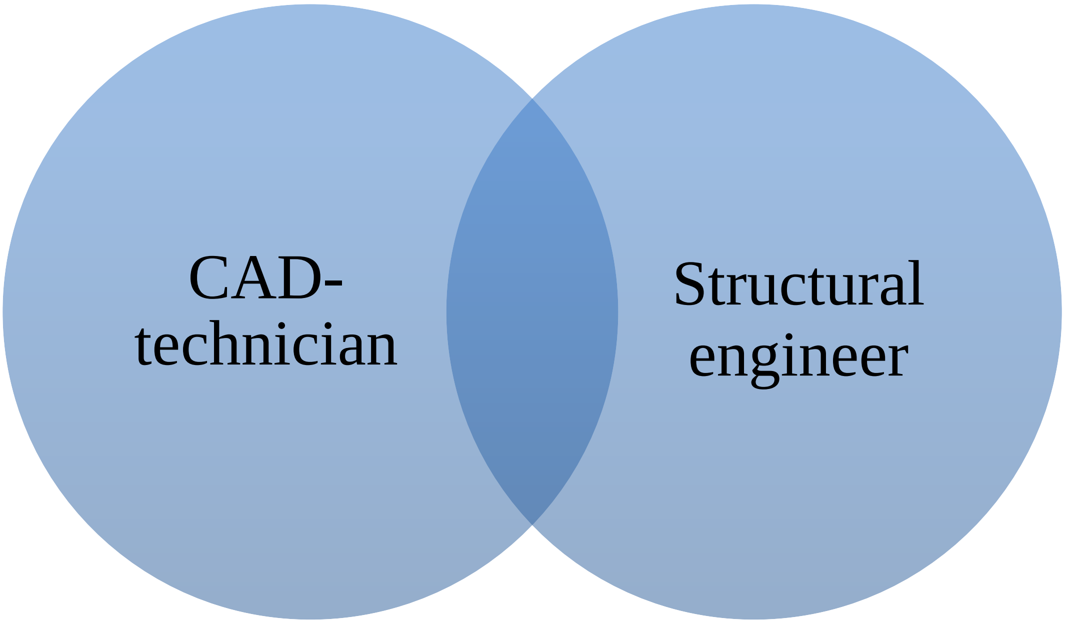

Integrated work of the CAD-technician and the structural engineer

Master of Science Thesis in the Master's Programme Structural Engineering and Building Technology

LISA BECKMAN
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Department of Civil and Environmental Engineering
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Concrete Structures
CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

The building sector consists of complex projects with a large number of actors represented. Much information must be arranged and communicated which together with the large number of actors creates a large need of an integrated work. A great challenge in the design phase is how to increase the integrated work of the CAD-technician and the structural engineer. The aim of this Master's project was to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer. The thesis focused on two important aspects: communication and linking knowledge. Linking knowledge is defined as the shared knowledge between two actors. Further on, in order to increase the integrated work between the actors their technical tools must be compatible. An additional aim was therefore to investigate the compatibility of Tekla Structures (TS) and SAP2000 (SAP), in order to highlight feasibilities and limitations of the use of the compatible link. A discussion of the important aspects and the investigation had the purpose to generate conclusions that facilitate a more integrated work of the CAD-technician and the structural engineer. The study was limited to the structural design process in the building sector in Sweden and the contribution from the CAD-technician and the structural engineer. The compatibility of TS and SAP was investigated with focus on export of panel and slab elements from TS to SAP. To meet defined aim, the method of the master thesis was divided into a preliminary study, a case study and a discussion. The case study resulted in feasibilities and limitation in the use of the compatible software. A discussion concerning a more integrated working method in the structural design phase was held. The importance of an integrated working process and what is defining an integrated work of the CAD-technician and the structural engineer were discussed. A discussion concerning the difficulties with an integrated work and related feasible solutions were also included. In conclusion, the use of compatible software can reduce the need of remodelling. Further on, linking knowledge was characterised and identified to be the solution to many problems in the integrated work. Finally, the use of compatible software, a well working communication in terms of manual communication as a complement to automatic communication and high linking knowledge was all described to facilitate a more integrated working process.

Key words: Communication, integrated work, integrated working method, CAD-technician, structural engineer, compatible software, linking knowledge, Tekla Structures, SAP2000, compatibility.

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SAMMANFATTNING

Byggsektorn utgörs idag av komplexa projekt med ett stort antal medverkande aktörer. En stor mängd information måste organiseras och kommuniceras och tillsammans med det stora antalet aktörer skapas ett stort behov av ett integrerat arbete. En stor utmaning i projekteringsfasen är att öka det integrerade arbetet mellan projektören och konstruktören. Syftet med detta mastersprojekt var att belysa fördelar och viktiga aspekter för att underlätta för en mer integrerad arbetsmetod för projektör och konstruktör. Projektet fokuserade på de två viktiga aspekterna kommunikation och delad kunskap. Delad kunskap kan definieras som den gemensamma kunskap som flera aktörer innehar. För att öka det integrerade arbetet mellan aktörerna måste deras tekniska hjälpmedel fungera mer integrerat. Mastersprojektet syftade därför till att djupare undersöka kompatibiliteten mellan Tekla Structures (TS) och SAP2000 (SAP) för att belysa vad som är och inte är möjligt i användandet av den kompatibla länken mellan programmen. En diskussion behandlande de två aspekterna och resultatet av undersökningen av den kompatibla lösningen syftade till att presentera slutsatser som kan underlätta för en mer integrerad arbetsmetod för projektören och konstruktören. Projektet var begränsat till projekteringsfasen i byggsektorn i Sverige, och bidraget från projektören och konstruktören. Kompatibiliteten mellan TS och SAP undersöktes med fokus på export av vägg- och plattelement från TS till SAP. Rapporten delades in i en preliminär studie, fältstudie och diskussion. Fältstudien resulterade i slutsatser om vad som är och inte är möjlig i användandet av de kompatibla programvarorna. En generell diskussion hölls därefter kring en mer integrerad arbetsmetod. Diskussionen behandlade vikten av en integrerad arbetsmetod och vad som definierar en integrerad arbetsprocess mellan projektören och konstruktören. Vidare diskuterades svårigheter med en integrerad arbetsmetod och dess lösningar. Slutligen presenterades att kompatibla programvaror, en välfungerande kommunikation, i form av manuell kommunikation som ett komplement till automatisk kommunikation, och stor delad kunskap är alla viktiga delar som kan underlätta för en integrerad arbetsmetod.

Nyckelord: Kommunikation, integrerat arbete, integrerad arbetsmetod, projektör, konstruktör, modell, kompatibla programvaror, delad kunskap, Tekla Structures, SAP2000, kompatibilitet.

Contents

Preface

This Master's project has been performed in cooperation with Reinertsen AB Sverige in Gothenburg during January to June in 2013. The project is a continuation of a previous bachelor's thesis carried out by Nilsson and Svennered at Reinertsen during spring of 2012. This Master's of science thesis is a finishing project in the Masters' degree programme Structural Engineering and Building Technology of the civil engineering program Väg- och vattenbyggnad at Chalmers University of Technology in Gothenburg, Sweden. The master program covers 120hp and the Master's thesis 30hp. The project is carried out at the Department of Structural Engineering, Concrete Structures, with the supervisor Rasmus Rempling.

In this project a case study was performed investigating the compatibility of Tekla Structures and SAP2000. The case study was performed at Reinertsen in Gothenburg. The study was performed on the basis of gained knowledge of the software through an internal education in SAP2000 at Reinertsen in February 2013 and a basic course in Tekla Structures at Tekla in Västerås in March 2013. Further on were conversations with representatives from the industry carried out during April. The dialogues were held with Simon Iversén at WSP and Daniel Rönnebjerg and Petra Sjöberg Gustavsson at COWI in Gothenburg.

We sincerely would like to thank Reinertsen AB in Gothenburg who gave us the opportunity to investigate and study this interesting subject at their office. We especially would like to thank our supervisors at the company Emanuel Trolin and Keyvan Zeidi who contributed with important guidelines and valuable advices during the project. We also would like to thank Rasmus Rempling at Chalmers who gave important inputs and supervision to the subject and the elaboration and setup of the report. Further on we would like to thank the opponents Olof Berglund and Alfred Emanuelsson for their great help and good advices during the project. In addition we would like to thank Simon Iversén at WSP and Daniel Rönnebjerg and Petra Sjöberg Gustavsson at COWI in Gothenburg who took their time and supported us with the understanding of today's situation in the design phase.

Finally, we would like to thank Tekla Västerås and EDRMedeso who sponsored our thesis with license for the software. Without their contribution the performance of this Master's project would not had been possible.

Göteborg, June 2013

Lisa Beckman

Gabriella Milveden

Notations

Below is brief a description of applied definitions, abbreviations and concepts.

Actor	A person who performs an action or operates in a consistency. In this context the CAD-technician and the structural engineer participating in the design phase.
Analysis & Design Model	A model created in Tekla Structures with the purpose of being used in analysis and design, described by nodes and analysis lines.
Analysis lines	Lines creating the Analysis & Design model in Tekla Structures.
CAD	Computer-aided Design.
CAD-technician	The actor who creates models for foremost creating of drawings.
Compatible software	Software that can exchange information and communicate with each other.
Element	Structural part in a model.
Export	Export of a model from Tekla Structures to SAP2000 based on the Open API-format.
Export-link	Software function which automates the export of 3D-models from Tekla Structures to SAP2000.
IFC	Industry Foundation Classes. A standard format used to communicate information between different platforms.
Integrated working method	The structural engineer and the CAD-technician working together instead of separate towards a common solution.
Manual communication	Information that is not automatic communicated (through e.g. a model) and instead is manual communicated.
Manual export	Export of a model from Tekla Structures to SAP2000 based on the file-format IFC.
Model	Assembled 3D-element(s) containing information about the material properties (material, density etc.).
Modelling techniques	Different ways of modelling in Tekla Structures.

Open API	Open Application Programming Interface, a format of which compatible links are based on.
Opening	An illustration of an opening describing for example a window.
Partly cut out	An element which is not totally cut through.
SAP2000 (SAP)	A 3D-modelling application used for analysis and design of a structural system. This software is used in the case study.
Structural engineer	The actor who performs the analysis and design of a structure.
Symmetry lines	Lines describing an element in SAP2000.
Tekla Structures (TS)	A 3D-modelling application used for modelling and creation of drawings. This software is used in the case study.
The design phase	A stage in the building project where appearance and dimensions of a structure is decided.
The structural design phase	A stage in the design phase where load-bearing system of the structure is decided together with design of the installations.
Warning count	Warning messages that may appear in Tekla Structures when creating the Analysis & Design model.
Warning/Error messages	Warning messages that may appear in Tekla Structures when the model is exported from Tekla Structures to SAP2000.

1 Introduction

The building sector consists of complex project processes with a large number of actors represented. A great amount of information must be arranged and communicated by the actors in the projects. Changes are continually done during a project and needs to be managed by information exchange between collaborate actors. The large number of actors and the great amount of information makes the need of an integrated work large. Development of engineering tools in the design phase has gone from working in a 2D-environment, to more and more perform the work in a 3D-environment. The new working environment has generated an innovative way of working with the possibilities to benefit from an integrated working method. An integrated working method could be described as a multidisciplinary process with actors working more integrated instead of separated to reach higher performance and benefits not possible for each individual actor working separately. Along with a more integrated working process two aspects have been identified to be important for the integration, namely communication and linking knowledge.

A great challenge in the structural design process today is how to integrate the work of the CAD-technician and the structural engineer. In Sweden today the actors are often represented by two different persons and their work is usually performed separated. Normally different but similar models are created by the actors. The development of computers has opened for a new way of working. One way of increase the integrated work of the structural engineer and the CAD-technician is to use compatible software. Compatible software can communicate and exchange information with each other and the use of compatibility opens for the possibility to use one common model for both the creation of drawings and for the analysis and design.

There is a number of compatible software on the market today, but the possibilities are more or less undiscovered and the number of users is few. Moreover are the purposes of the two models created by the CAD-technician and the structural engineer different. In other words, there are still some obstacles left along the way to a more integrated work between the CAD-technician and the structural engineer in the design phase.

1.1 Aim and objective

The aim of this Master's project is to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in the structural design phase. The Master's project focuses on two important aspects: communication and linking knowledge.

Moreover, development of integration of technical tools is of importance in the work towards a more integrated working method. The master project therefore includes a deeper investigation of two compatible software in the design phase. The compatibility of Tekla Structures and SAP2000 is studied through a case study which examines the export of panel- and slab elements from Tekla Structures to SAP2000. The case study aims to highlight feasibilities and limitations of the compatible link between the software. Further on, a discussion concerning the feasibilities and limitations is held with the purpose of resulting in recommendations for the export.

The objective of the case study is to supply the user with a manual including instructions for optimising the use of the compatible link between the programs. The study is a continuation from a previous project carried out in 2012 by Nilsson and Svennered (Nilsson & Svennered, 2012).

Finally, the two aspects communication and linking knowledge and the investigated compatible link are together discussed in order to generate conclusions that facilitate a more integrated work of the CAD-technician and the structural engineer in the structural design phase.

1.2 Research questions

- Why is an more integrated working method important in the structural design phase?
- What benefits could be generated from a more integrated work?
- What defines an integrated working method of the CAD-technician and the structural engineer?
- What difficulties have been identified in a more integrated working process?
- What feasible solutions can be found to manage the identified difficulties?

1.3 Limitations

In this master project the building sector in Sweden is treated and focus will be held on the structural design process. Only contribution from the CAD-technician and the structural engineer is investigated, which includes modelling, analysis and design of a structure. In the project it is assumed that the CAD-technician and the structural engineer are represented by different persons. Further on, it is assumed that the CAD-technician is the one that performs the modelling in Tekla Structures, while the structural engineer performs the analysis and design in SAP2000.

The compatible link between the technical tools SAP2000 and Tekla Structures are investigated. The thesis discusses mainly the export of concrete panel and slab elements from TS to SAP. To read about the export of beams and columns, see the bachelor thesis by Nilsson and Svennered (Nilsson & Svennered, 2012). The models are idealised as concrete without reinforcement which consequently are exported and analysed without the influence of reinforcement bars. The reinforcement does not influence the analysis lines, and should therefore either not influence the export.

The models are exported by the *Export*-link and the export is performed in one way only – from TS to SAP. A reason why the model not is imported to TS again is since the thesis only is investigating *Export* of concrete panels and slabs without reinforcement. SAP is not able to design reinforcement in concrete panels and slabs, and dimensions of element cannot be changed.

Further on, the analysis and design are performed in SAP, while the overall modelling mainly is done in TS. From the analysis in SAP, results could be used for either hand-calculations or further analysis with other software. Finally, as a result of the bachelor thesis by Nilsson and Svennered loads and boundary conditions are recommended to be applied to the model in SAP (Nilsson & Svennered, 2012).

1.4 Method

To meet the defined aim, the master's project was divided into three parts. In the following paragraphs the used methods are described and motivated. Further on, the results of the application of methods are shortly discussed.

A preliminary study was performed to gain knowledge about the design phase, the working process of the CAD-technician and the structural engineer and an integrated working method. Moreover was the preliminary study used to identify and study important aspects in this integration. The preliminary study was firstly based on only a literature study in order to gain knowledge about the design phase and the work of a CAD-technician and a structural engineer. Further on, the advantages of an integrated work of the two actors was studied more carefully, and problems associated with an integrated working method. The literature was to some extent vague and it was hard to collect relevant information. This could be explained by the fact that it is an upcoming subject and few authors have written about it. In order to gain update facts about how companies in Sweden today work and what they are expecting of the future, dialogues with representatives from the industry were performed and included in the preliminary study. The outcome from the dialogues also acted as an aid to distinguish problems related to the use of compatible software. However, the way of working is individual for each company and the dialogues with representatives gave therefore no general picture.

The previous project performed at Reinertsen was used as a basis, and acted as a staring-point for the section treating the compatibility (Nilsson & Svennered, 2012). In addition, software learning of Tekla Structures and SAP2000 were used in order to gain basic understanding and knowledge about the software and about the compatible link. The knowledge in TS was deepened with a course at Tekla Sweden in Västerås. Tutorials together with the course in TS and an internal course in SAP gave enough knowledge about the tools to start the case study.

The investigation of the compatibility of TS and SAP was performed by a case study in order to study the export more closely and to identify feasibilities and limitations of the compatible link. Furthermore the case study aimed to create a manual including instructions and recommendations for optimising the use of the *Export*-link. The method was chosen since it was applicable on the problem and generates a clear understanding of the feasibilities and limitations. The case study was performed by creating a model in TS and export it to SAP to perform an analysis. A more detailed approach is presented in chapter 3. In order to easily identify feasibilities and limitations of the compatibility, the export was divided into three studies. Recommendations were presented after each study which were supposed to work as guidelines of respectively modelling tasks. The recommendations were furthermore used to clarify the distribution of responsibility for the CAD-technician and the structural engineer and could be applied in an integrated working method. Moreover the results were discussed resulting in recommendations for the usage. The recommendations were very specific for the use of the compatible link between TS and SAP, but they were evaluated to be able to be applied in a more general case. Thereby, they can be used as a method for an integrated work. Recommendations given for the case study gives to some extent information about which actor that should perform what task in the common model. Though, they are not covering guidelines of how the manual communication should be performed. This should preferable be included in an integrated working method in order to avoid double work or loss of information.

Finally, the two important aspects communication and linking knowledge are discussed together with results from the investigation concerning the compatible link. In order to end up in conclusions that facilitate the integrated work of the CAD-technician and the structural engineer the discussion is divided into three parts, the importance and difficulties with a more integrated working method and finally feasible solutions.

1.5 Key results

The aim of the Master's project is to highlight both possibilities and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in the design phase. The Master's project focus on the two important aspects: communication and linking knowledge which together with a deeper investigation of Tekla Structures and SAP2000 generated the following key results:

- An integrated working process can be described in terms of manual communication and compatible software.
- The case study resulted in feasibilities and limitations of the export and the conclusion that the use of the compatible link between TS and SAP would increase the integrated work between the CAD-technician and the structural engineer.
- Linking knowledge is the solution to many identified difficulties in a more integrated working process.
- Manual communication should be used as a complement to automatic communication.
- To facilitate a more integrated work manual communication, compatibility between software and linking knowledge are important means.
- Further studies are needed concerning development of the manual communication, development of the compatible link and corresponding manuals. Further on, it is recommended to improve the available standardised file format. Finally, a recommendation is presented about educating in linking knowledge.

1.6 Thesis outline

This Master's project consists, in addition to the introduction chapter, of four chapters.

Chapter 2 is based on literature and conversations with representatives from the industry. It describes the stages in a building project and the technical development in the structural design phase. Further on two actors, the CAD-technician and structural engineer, their working process and their tools are described. The concept integrated working method is described followed by two important aspects, communication and linking knowledge.

Chapter 3 describes purpose, approach and result of the case study treating the compatibility of Tekla Structures and SAP2000. The case study is divided into three studies including several exports from TS to SAP. For each export recommendations are given. Each export is overall described in the report and a more detailed implementation of the case study is presented in Appendix I. Further on, a summary of results from the case study including feasibilities and limitations are presented. Finally, the results are discussed followed by a presentation of recommendations optimising the use of the compatible link.

Chapter 4 presents a discussion concerning a more integrated working method in the structural design phase. The importance of an integrated work and the definition of an integrated work of the CAD-technician and the structural engineer are discussed. Further on, difficulties in a more integrated working method are identified and discussed. Finally, feasible solutions to manage the difficulties are presented.

Chapter 5 presents a summary and overall conclusion that reflecting the aim of the Master's project. Further on are solutions given to researches questions in chapter 1.2. Finally are conclusions that facilitate an integrated working process of the CAD-technician and the structural engineer presented.

Appendix I contains a detailed implementation of the case study.

Appendix II contains a manual including instructions and recommendations for optimising the use of the compatibility between TS and SAP.

2 The design process

In the following chapter results from literature study and dialogues with representatives from the industry are presented. The chapter includes an introduction of the working process in the building sector today with focus on the design process. Further on, the work of the CAD-technician and the structural engineer and their technical tools are described. The chapter is finished with a description of an integrated design method, important aspects related to an integrated work and compatible software.

2.1 From idea to product: stages in a building project

A building project can, according to Nordstrand and Revái, roughly be divided into three main stages: Investigation and program work, design phase and production (Nordstrand & Revái, 2002). In Figure 2.1 the main stages in a building project can be seen and this master project has as mentioned focus on the design phase.

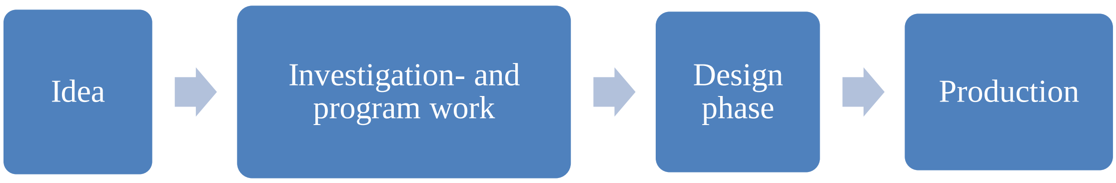

Figure 2.1 Stages in a building project

In the design phase the appearance and the dimensions of the structure is decided, as well as the formation of the detailing. The design phase can be divided into three stages, see Figure 2.2. The stages are, the *design formation* – where the structure gets the overall appearance, the *structural design* – where the load-bearing system of the structure is analysed together with the design of the installations and finally the *detailing* – where the last dimensioning, choice of material and execution are decided. The design phase results in, among others, drawings and reports. The work in the design phase is done stepwise and the CAD-technician and the structural engineer play an important role in this phase (Nordstrand & Revái, 2002). The CAD-technician could be described as the actor who creates models with purpose of creating drawings, while the structural engineer is the actor who creates models that aims to be used for the analysis and design. An actor could be described as a person who performs an action, which in this context is the CAD-technician or the structural engineer participating in the design phase. A model is in this report defined as 3D-element or several assembled 3D-elements containing information about the material properties (material, density etc.).

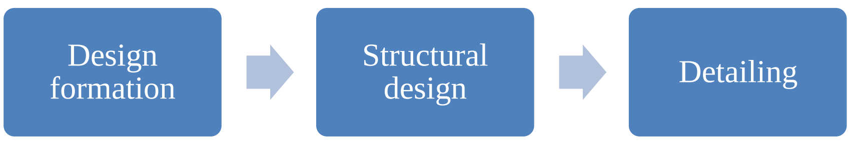

Figure 2.2 Stages in the design phase.

2.2 Development of technology in the design phase

During the last decades, the working process in the design phase has been highly developed. Wikforss describes that the working process mainly has progressed from using 2D-modeling to increasingly use 3D-modeling. Nowadays are the use of 3D-modeling more spread and the usage increased. More information can be connected to the model and the work can be performed more integrated (Wikforss, 2003). The development is illustrated in Figure 2.3.

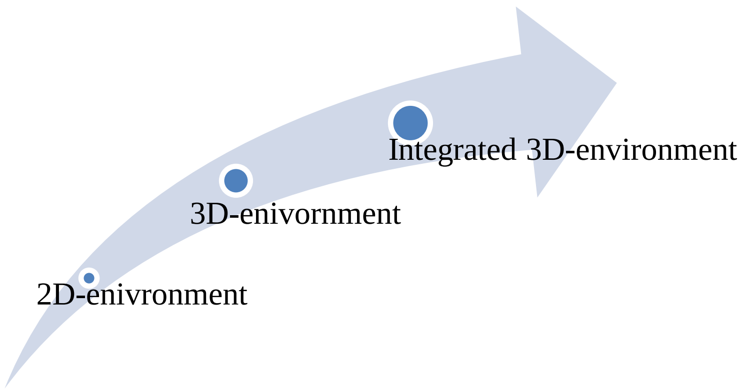

Figure 2.3 The development of the working environment.

Back in the 1960's pencils, drawing tables and calculation machines were common used tools in the building sector and in the 1970's systems used for both drawings and calculations were introduced. The development of the personal computer in the beginning of 1980's created new possibilities for the work in the design phase, AUTO-CAD was introduced for architects and engineers and 3D-constructions could be created in 2D views. Today both computers and software have developed and new solutions make it possible to work in a 3D-environment. Information can be connected to the model by the file format IFC (Industry Foundation Classes) which is a standard format used to communicate between different platforms. Through the file format a higher exchange of information between actors in the building sector is possible (Wikforss, 2003). According to Eastman, Teicholz, Sacks and Liston a model containing information about the structure is called a BIM-model. Through the use of Building Information Modelling (BIM), information for the whole building process could be connected to the model and several disciplines can work together in a common model. BIM is a basic and different way of create, use and share information about the lifecycle of a structure (Eastman, Teicholz, Sacks & Liston, 2011).

2.3 The working process and the technical tools of the CAD-technician

A CAD-technician has education in the field of building construction with the understanding of calculation and design of a structure[1]. With the technical development, the working tools used by the CAD-technician have proceeded from 2D-modelling software to 3D-modelling software (Nilsson & Svennered, 2012). According to Iversén

[1] Simon Iversén CAD-coordinator WSP, dialogue 12/4-2013

the CAD-technician has the main task of creating models to present drawings needed in the design process[2]. Most of the work is nowadays performed with the help of computers. Besides creating models, also easier calculations, material specifications and technical descriptions can be part of the job assignments for the CAD-technician. Further on, Nilsson and Svennered describe how the working process of the CAD-technician highly depends on the development of technical tools. Nowadays, the CAD-technician can both faster and more dynamic produce models and drawings. In the market today are a number of software used for 3D-modeling. The modelling techniques in these software are more effective as regards time with more accurate connections between plane and section. Moreover, the software enables better visualisation of the model and since more information can be added to the model it can constitute as information-bank during the entire project (Nilsson & Svennered, 2012).

One common used software allowing for creation of structural 3D-models is Tekla Structures (TS). The program is, according to TEKLA, adjusted for BIM and is able to create detailed, complex 3D-models of structures. The whole building process can be covered by TS models, from conceptual design and fabrication to erection and construction and can be used for modelling of both steel and concrete structures (TEKLA [1], 2013). A full configuration with tools for all design phases is available in TS. The modelling function, the output function and the collaborations properties defines the different areas in which Tekla Structures can be used. These areas make it possible for the user to add loads, create detailed connection and easily create drawings and reports. Further on it is possible for the model to be used simultaneous by several users and to interface the model with other tools (TEKLA [2], 2013).

2.4 The working process and technical tools of the structural engineer

A structural engineer is usually a person with deep educational knowledge in structural engineering and who has a great understanding for the structural behaviour[3]. The structural engineer has, according to Nilsson and Svennered, the main responsibility for the analysis and design of a structure. Modelling is also part of the work of a structural engineer where the created model constitutes as a base for design and analysis. Moreover, the work includes creation of technical documentation and calculation reports (Nilsson & Svennered, 2012).

Before the use of technical computer tools calculations were mainly performed by hand. This is, according to Iversén[2], still to some extent done today. Nowadays 2D software are often used for the calculations but the use of 3D-software increases. A used modelling application for the analysis and design of a structural system is SAP2000 (SAP). The application can, according to SAP2000, handle everything from basic to advanced systems modelled in 2D and in 3D. The structural system is modelled, analysed, designed and optimised within the same user interface SAP2000 [1], 2013). The result of the analysis can among others be displayed graphically by deformed geometry based on load, animation of deflections or by shear- and moment diagrams (SAP2000 [2], 2013).

[2] Simon Iversén CAD-coordinator WSP, dialogue 12/4-2013
[3] Daniel Rönnebjerg structural engineer COWI, dialogue 17/4-2013

2.5 Integrated working method

The building sector is, according to Wikforss, in one way unique. Specific for the industry are the complex and large project processes with a high variety of actors from different fields with the need to be coordinated. Much information must be communicated, stored, arranged and distributed, hence the project can become highly intense and complicated. The fact that many actors often are involved, together with the large need of information exchange, makes the need of integrated work in the building sector larger than for other industries. In building projects today a more separated working procedure with reporting of results in different kinds of documents is often used. This results in loss of information and unnecessary duplication of work (Wikforss, 2003).

An integrated working method could, according to Energy Design Recourses, be described as a multidisciplinary process were actors (architects, engineers and contractors) can integrate their work to reach higher performance and benefits that is not possible for each individual actor working separately. A integrated work bring together disciplines from the building industry in a new way of working which can create solutions and reach goals that otherwise would not have been reached (Energy Design Recourses, 2006). As a result, new forms of cooperating will develop and by overlapping gaps between actors an integrated working method could increase the productivity and effectivity in the design phase (Wikforss, 2003). An integrated working method could summarised be described as a method where all involved actors work together instead of separate towards a common solution.

According to Kozlowski an integrating working method is created by better communication and more planning, and can result in improved and less expensive projects. It is used for optimising the project at the same time as minimising the cost. The method has been available for a long time, but few actors have enough understanding of it. A building project could be seen as a system consisting of smaller systems. Integrated work assumes that all systems are affected by other systems and thereby rely on each other in order to reach higher effectivity. The integrated design method needs to be included early in the design. The reason for this is that the work of actors like HVAC-engineers and the structural engineer is influencing each other, and as well the result of it. What makes an integrated working method different to common used linear processes is the importance of well working and continuous communication between involved actors in the project. Kozlowski states ”*When communication breaks down, so does the design and construction process”.* Kozlowski describes that communication is needed, and especially communication in an early stage (Kozlowski, 2004).

Further on, Luiten and Tolman means that a more integrated way of working could eliminate wasteful activities such as time-consuming copying of material together with the reinterpretation of documents. It could as well lead to a better utilisation of available information generated from the increased use of computer applications (Luiten & Tolman, 1997).

2.6 Important aspects related to a more integrated working method

An integrated working method places the actors in new situations to be handled. This thesis raises two important aspects related to this integration, linking knowledge and communication, which are described in this chapter.

The lack of understanding of the design process may lead to irrationally introduced changes or changes that are missed to be spread to all affected actors (Hegazy, Zaneldin & Grierson, 2001). The lack of linking knowledge is described by Mokhtar, Bédard and Fazio as a factor resulting in inadequate communication (Mokhtar, Bédard & Fazio, 1998). Linking knowledge could in the structural design phase be explained as the shared knowledge of the CAD-technician and the structural engineer, illustrated in Figure 2.4.

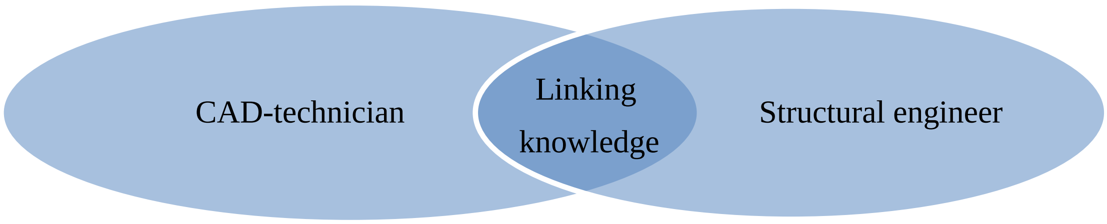

Figure 2.4 Linking knowledge is the shared knowledge of the CAD-technician and the structural engineer.

In order to work more integrated, the CAD-technician needs to be aware of how the model is used for design and analysis, and the structural engineer needs to have understanding of how the model is created to generate drawings. Both the CAD-technician and the structural engineer need to have better knowledge and understanding of each other's work and technical tools. Linking knowledge is essential in order to report on changes to other involved actors. Mokhtar, Bédard and Fazio describe that each involved actor must be aware of how changes done by another actor affect their own design. This means that also knowledge about the input of another actors work is important. For a company working with larger projects, containing a very large amount of interlinked data, linking knowledge may be crucial (Mokhtar, Bédard & Fazio, 1998).

Zaneldin, Hegazy and Grierson believe that to enable a successful integrated work the communication between different actors play a major role. Changes affecting several actors in the design phase are continually done during a building project and needs to be managed. With lack of communication, changes are poorly communicated which results in a more costly design process. A vague communication with frequently introduced changes can also affect the quality of the result (Zaneldin, Hegazy & Grierson, 2001). Further on, Wikforss means that a successful information exchange could overlap distances in the cooperation of the communication between actors. Further on, loss of information together with wasteful activities could be decreased (Wikforss, 2003). Communication between different disciplines can be performed either manual between actors or automatic between computers as electronic exchange.

According to representatives[4] from the industry most of the communication today is performed manually between actors. Videoconferences, groupware or whiteboard discussions could be used to coordinate the work and the manual communication between the actors in a building project. Further on, Zaneldin, Hegazy and Grierson describes that electronic exchange through Internet increases the amount of information that can be communicated, compared to old manual methods (Zaneldin, Hegazy & Grierson, 2001). However, Hegazy, Zaneldin and Grierson describe how manual communicated changes have shown to be time-consuming, costly and ineffective. Actors may forget to inform about changes and may presume that other disciplines are unaffected by the changes. This misunderstanding will generate inadequate coordination between disciplines as well as conflicts and mismatches (Hegazy, Zaneldin & Grierson, 2001).

Wikforss means that a more integrated working method creates new needs for systems of information exchange (Wikforss, 2003). Moreover, Luiten and Tolman mean that with an increased use of computers as working tools in the design phase it is instead more logical to communicate through computers. Computer-based technical tools are aimed to increase the integration in the design phase by automating the communication between actors in the process. By making automation and integration of tools possible, wasteful activities such as unnecessary effort and human errors could in higher extend be avoided (Luiten & Tolman, 1997). A further step in the communication through computers is the use of compatible software. Compatible software can, according to Nilsson and Svennered, exchange information and communicate with each other (Nilsson & Svennered, 2012).

2.7 Compatible software as a technical tool

Previous way of working was to a larger extent based on that each actor worked separated and a lot of work was unnecessary redone (Wikforss, 2003). Usually the CAD-technician and the structural engineer are represented by two different persons with separate working processes. However, as mentioned earlier, two similar models are used by both actors. By using compatible software, Nilsson and Svennered mean that possibilities are created for a more integrated working process of the structural engineer and the CAD-technician. Instead of creating two similar models, one common model could be used in the design phase by the use of compatible software (Nilsson & Svennered, 2012).

Tools and applications that are compatible can exchange information and communicate with each other. The exchange of information can, according to Nilsson and Svennered be accomplished either by manual export with compatible file format or by links. Through manual export, the model can be exported with the IFC format (Nilsson & Svennered, 2012). The compatible file format IFC (Industrial Foundation Classes) is a global work of standardised information for different parts in a building project. IFC has the possibility of describing components in a structure with the base of geometry, dimensions and attributes among others (Wikforss, 2003). According to Nilsson and Svennered the manual export enables for the software to be installed on different computer. This however, is not possible for the use of a compatible link where both software must be installed in the same computer. Program links are

[4] Daniel Rönnebjerg structural engineer and Petra Sjöberg Gustavsson CAD-technician COWI, dialogue 17/4-2013

developed to suit specific software. The links are based on “Open API” (Open Application Programming Interface). “Open API” is formed in order for product developers to create programs compatible with other software (Nilsson & Svennered, 2012).

The two previous mentioned software Tekla Structures and SAP2000 are example of compatible software. Information that can be transferred between TS and SAP are wide. Nodes, slabs, walls, loads, materials and cross sections are all examples of information that are compatibly for the transformation from TS to SAP. Changes made in SAP which can be imported to TS are changed section, member displacements and design results example of changes that can be imported (SAP2000 [3], 2013). Further on, Nilsson and Svennered describe how the information exchange between Tekla Structures and SAP2000 either can be manually performed or integrated by a specific link. Possible links for the information exchange are the *Export* and *Open Application*. Previous studies by Nilsson and Svennered resulted in recommendations of using the *Export*-link[5] for the first transfer of information between TS and SAP while the *Open Application*-link is recommended to be used when changes had been performed. The manual export is not recommended to be used for the compatible solution TS and SAP (Nilsson & Svennered, 2012).

According to representatives[6] from the industry compatibility between software are infrequently used. The work with separated working tools is assumed to be both easier and faster and secures correct results. The difficulty is the fact that the models are created with different purposes. Kurowski means that the main problem is the differences in requirements of CAD (Computer-aided Design) and FE-analysis geometries. CAD geometries must be fully described while the FEA geometries must be idealised and simplified (Kurowski, 2000). Moreover, representatives[6] stress the difficulties in differences in level of details, the CAD-technician must model details in an early stage while the structural engineer is designing details in a late stage of the project.

Further on, Wikforss describes how each working tool defines information and presents results most adjusted for that specific program. For information to be shared and adopted in other software, materials, components and processes needs to be standardise (Wikforss, 2003). Further on, in addition to the infrequently use of compatible solutions is the lack of information in forms of manuals and descriptions about different links. In the upcoming chapter, a case study treating the previously described compatible link *Export* between Tekla Structures and SAP2000 are presented. Feasibilities and limitations together with instructions and recommendations for the use are presented in order to increase the knowledge and optimise the use in the integrated working process.

[5] The Export link is a software function which automates the export of 3D-models between software.
[6] Simon Iversén CAD-coordinator WSP, dialogue 12/4-2013, Daniel Rönnebjerg structural engineer and Petra Sjöberg Gustavsson CAD-technician COWI, dialogue 17/4-2013

3 Case study: Compatible link between software

In the following chapter a case study treating the compatible link between Tekla Structures (TS) and SAP200 (SAP) is presented. The case study is introduced with a short introduction, described purpose and an outline of the work. Further on, a general approach is presented together with a short description of used software. The chapter includes three studies with presented aim, approach, result and recommendations of each study.

3.1 Introduction

One way in increasing the integrated work of the CAD-technician and the structural engineer is by take use of compatible technical tools. Today, several software are compatible, but the knowledge about these connections is still small and the users are few.

A structure is generally consisting of walls and floors, which in a model is modelled as panels and slabs. Panels and slabs could be described as structural elements in a model. In this study panels and slabs are exported from TS to SAP containing information about specific material properties (material, density etcetera). Walls and floor usually contains of irregularities such as windows and openings for various installations. These irregularities are normally modelled as simple opening in a panel and slab. The compatibility of TS and SAP is investigated through a case study, which is divided into three sub-studies. The sub-studies are: "Export of panel and slab elements", "Export of openings modelled in panel and slab elements" and "Export of connected panel, slab, beam and column elements". The approach is shortly described in this chapter. For a more detailed description of the approach and the result the reader is referred to Appendix I: *Detailed presentation of implementation of the case study.* To read about the export of line elements, i.e. beams and columns, see the Bachelor thesis "*Integrerad arbetsprocess mellan projektör och konstruktör*" by Nilsson and Svennered (Nilsson & Svennered, 2012).

3.1.1 Purpose and objective

The purpose of the case study is to investigate the compatibility of Tekla Structures[7] and SAP2000[8] in order to identify feasibilities and limitations of the compatible solution. The objective of the study is to generate recommendations about preferable modelling techniques[9] and, when it is of importance, recommendations about which actor that should perform a specific task. The recommendations will be collected in a manual, which is presented in Appendix II: *Manual of the export from Tekla Structures to SAP2000*.

To identify feasibilities and limitations, the following questions was studied:

- How should a single surface, a panel or a slab element, be modelled in order to enable an export from TS to SAP?

[7] A 3D-modelling software used for the creation of drawings, used in the case study
[8] A 3D-modelling application for the analysis and design of a structural system, used in the case study
[9] Modelling technique is different way of modelling in Tekla Structures and SAP2000

- How should connected elements be modelled in TS in order to generate a connected model in SAP?
- How should openings be modelled in panel and slab elements in TS in order to be exported to SAP?

3.1.2 Outline

The chapter is divided into three parts:

- Export of panel and slab elements.
- Export of openings modeled in panel and slab elements.
- Export of connected panel, slab, beam and column elements.

To make the presentation of the study clearer, these studies are divided into a number of smaller studies. Each smaller study is presented on one spread and is described by the lines of purpose, approach, and result. It is finally summarised by short conclusions and necessary recommendations.

3.1.3 General approach

The case study was performed with the *Export*-link. The general approach can be described by the process below, see Figure 3.1.

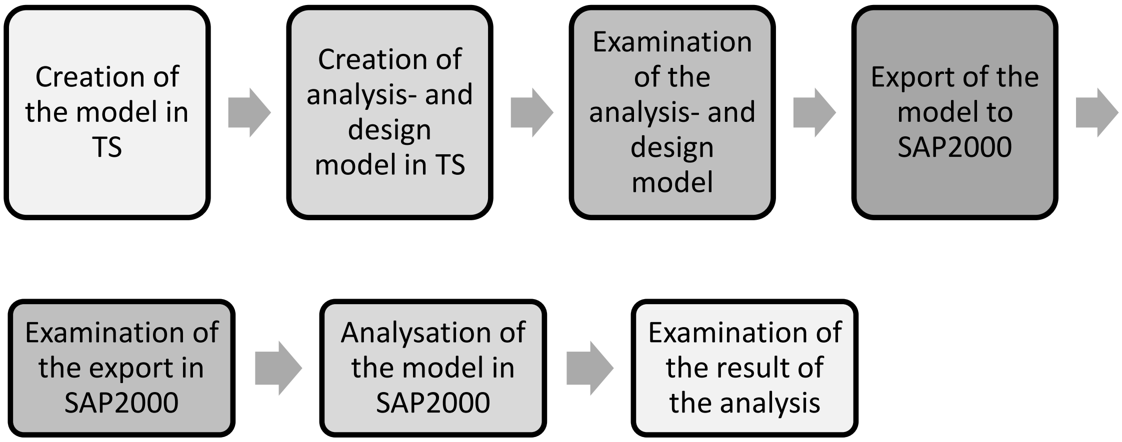

Figure 3.1 A description of the general approach used in the case study.

The model was created in TS using various modelling techniques where properties for each element were assigned to the model. The modelling technique used in each study was depending on type of model, together with type of investigation, see each case study for more information. Panels and slabs where made of concrete C25/30 modelled with a thickness of 400 mm for all studies.

The *Analysis & Design model* was created in TS and the analysis lines were examined. An *Analysis & Design model* is a model created in Tekla Structures which consists of nodes and analysis lines, and analysis lines could be describes as the lines that creates the *Analysis & Design model* in Tekla Structures. According to Nilsson and Svennered the analysis lines in TS correspond to symmetry lines in SAP2000 which means that for the model to be fully exported the analysis line must be correctly created. The symmetry lines could be explained as the lines that describes an element in SAP2000. *Warning counts* appear if it arises any errors during the creation of the *Analysis & Design model*, see Figure 3.2. *Warning counts* in TS must always be checked and if the user considers it necessary, the model should be adjusted (Nilsson & Svennered, 2012).

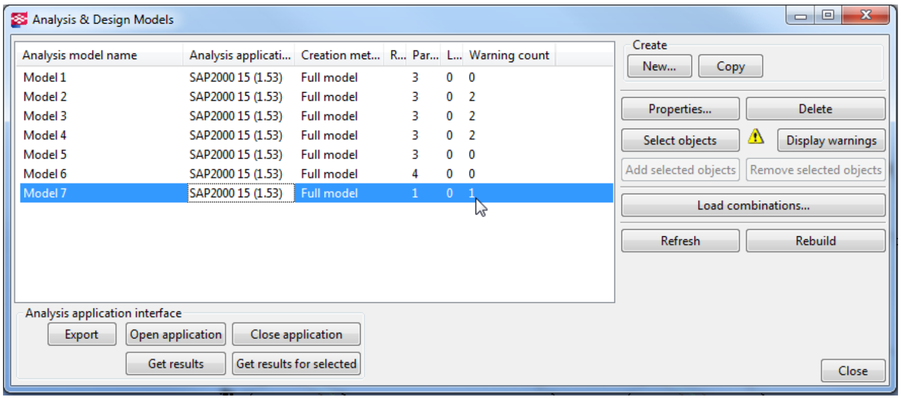

Figure 3.2 Warning counts created during the creation of the Analysis & Design Model.

The model was exported to SAP2000 by the *Export*-link and examined in order to determine the quality of the export. For example was the geometry and material properties checked. It is of high importance to check the *warning/error* messages that appear in TS when the model is exported, see Figure 3.3. SAP opens automatically in front of TS when the *Export* is performed. These messages can therefore easily be missed.

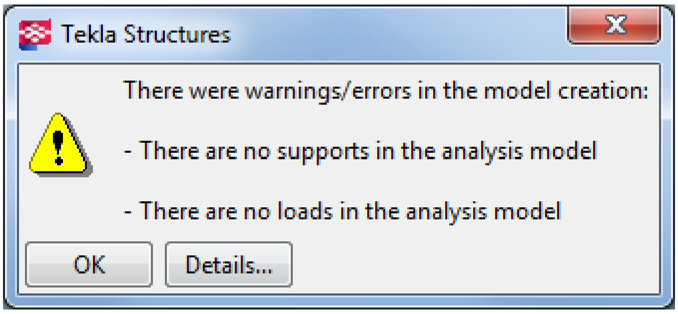

Figure 3.3 Warning/errors created during the Export.

When the model was exported from TS to SAP, SAP was automatically opened and an .sdb-file was created and saved. For each time the *Export*-link was used a new .sdb-file was saved. Nilsson and Svennered describe how the *Export*-link only could be used for the first export of the model, otherwise the old model will be replaced by the new one and all settings and changes made in SAP will be lost. For the second export, and for the rest of the design process, it is instead recommended to use the *Open Application*, for which SAP is automatically opened with the latest version of the exported file. *Open Application* is however out of the scope of this thesis.

Loads and boundary conditions were assigned to the model in SAP. The model was analysed in order to verify the export. For the first static analysis the mesh option chosen by SAP was kept. SAP2000 does not have a default auto meshing but the program generates a mesh based on geometry and nodes of the model. If the mesh was inappropriate another meshing option was chosen until an acceptable mesh was achieved. If no mesh option is recommended for the sub-studies, the auto mesh chosen by SAP was used, an acceptable mesh option is otherwise recommended. The result generated in SAP could have different purposes from case to case, but the most common aim of the result is to identify sectional forces for the use in further design procedures. The requirement of the quality of the mesh depends on how the result is going to be used in further analysis. In the case study the result of the analysis in SAP is used in order to verify the exported model and an appropriate mesh option is described by rectangular and regular elements.

3.1.4 Software

The software used in the case study where:

- Tekla Structures 17.0
- SAP2000 Ultimate 15.1.0
- *Export* function *version 15* (downloaded from *Tekla Extranet*) [*TeklaStructures_x64_SAP2000v15_153_setup*]

3.2 Export of panel and slab elements

Modelling and analysing panel and slab elements is a fundamental work in the design phase. The purpose of this study is to identify feasibilities and limitations of the export of panel and slab elements from TS to SAP.

The sub-study is divided into three studies:

- Export of a panel element.
- Export of a panel element in connection to a slab element.
- Export of connected panel and slab elements.

3.2.1 Export of a panel element

Purpose

The purpose of the study was to examine if the panel was exported from TS to SAP. The study also aimed to investigate if the orientation together with information connected to the model was exported, see Figure 3.4.

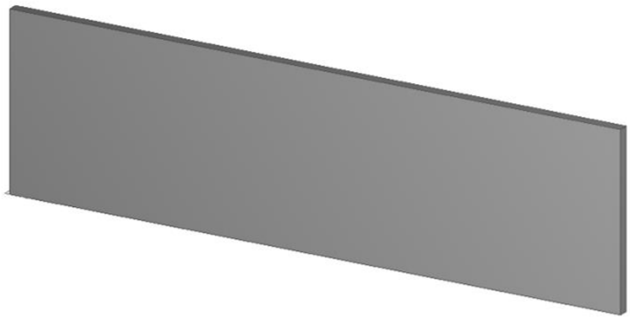

Figure 3.4 A model of a single concrete panel modelled in TS and exported to SAP.

Approach

The concrete panel was modelled in TS by using the *concrete panel*-tool. The information connected to the model was examined after the export. This study did not include any analysis of the model.

Result

The model was able to be exported to SAP. Geometry, defined material properties and the orientation of the model was correctly exported.

Conclusion

Information connected to a panel element and its orientation is exported.

Recommendations

- It is recommended to always control the *warning counts* that appear during the creation of the design- and analysis model, also to check the *warning/error messages* that appear for the export.

3.2.2 Export of a panel element in connection to a slab element

Purpose

The purpose of the study was to examine if a panel element in connection to a slab element was exported as connected elements, see Figure 3.5.

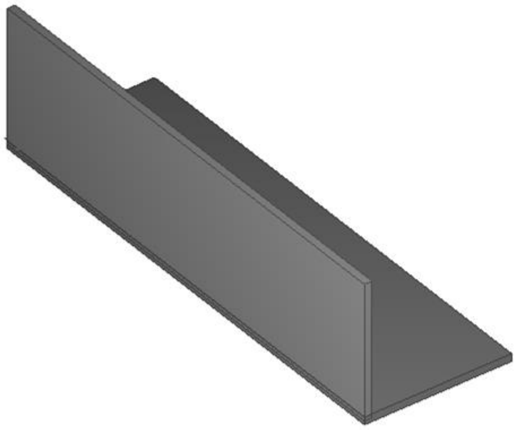

Figure 3.5 A panel element in connection to a slab element modelled in TS.

Approach

The slab was modelled with the *concrete slab*-tool and the panel was modelled with the *concrete panel*-tool upon the slab. The surface of the panel was connected to the surface of the slab, see Figure 3.6. The model was analysed in SAP influenced by the dead weight.

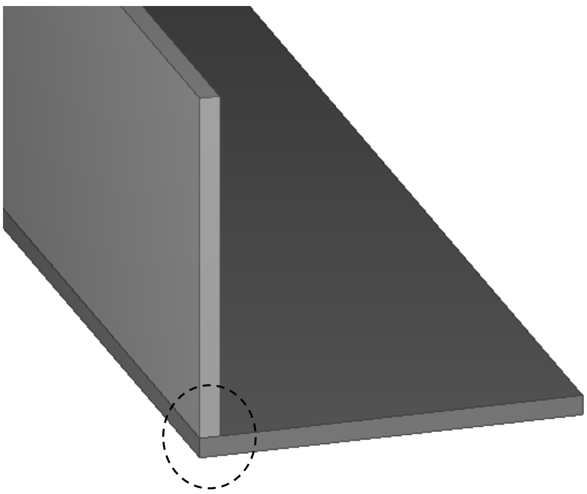

Figure 3.5 Connected surfaces of the concrete slab and the concrete panel.

Result

The *Analysis & Design model* was created and it was noted that the elements had separate analysis lines, see Figure 3.6. This resulted in two separate elements exported to SAP2000. The model was modified in TS into a model where the elements instead were connected in their centre lines. In the *Analysis & Design model* the two elements were now sharing an analysis line, see Figure 3. Another way of solving the problem is to directly modify the created analysis line in TS by manually moving the handles of the analysis lines.

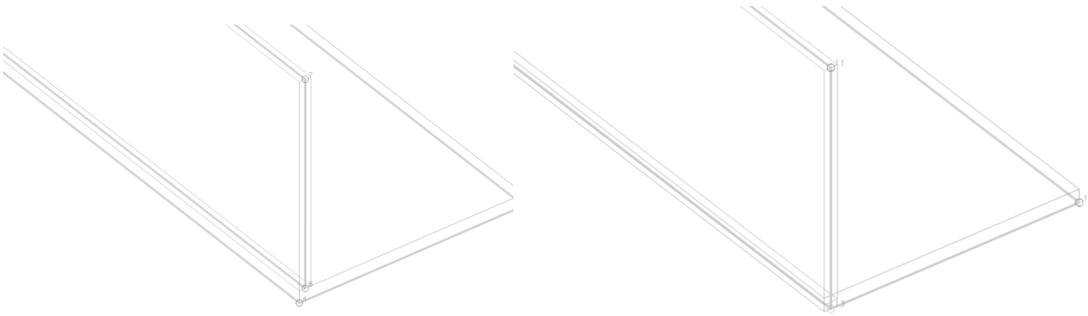

Figure 3.6 To the left: a model containing elements with not shared analysis lines. To the right: a model containing elements with shared analysis lines.

Because of how the analysis lines are created in TS the dimensions of the exported model in SAP may be somewhat changed. However in this case, the difference in dimensions was relatively small and could be ignored.

The result of an analysis in SAP showed that the panel and the slab were exported and connected properly.

Conclusion

Panel elements in connection to a slab element are exported as connected elements if they share an analysis line in TS.

Recommendations

- Connected elements must share analysis lines in TS in order for the elements to be exported as connected elements. If the *Analysis & Design model* not is created with shared analysis lines this could be performed by manually moving the handles of the analysis lines into shared analysis lines.
- To generate a model with correct dimensions the position of the analysis lines are recommended to be controlled by foremost the CAD-technician in TS.

3.2.3 Export of connected panel and slab elements

Purpose

The purpose of the export was to examine if the method of modelling was affecting the export of a structure constructed by several panel and slab elements in connection to each other, see Figure 3.7.

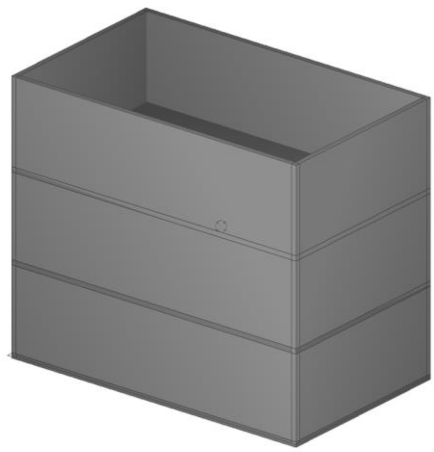

Figure 3.7 A model with several panel and slab elements in connection to each other.

Approach

The study was treated by two models modelled with different modelling methods. The models differ in the extent of the panels. The models was analysed in SAP influenced by a surface load applied on the top slab. The resulting stresses of each model were compared.

In the first model three panels were placed upon each other, see the left figure in Figure 3.8. In the second model the panels were spanned all the way from the bottom to the top, see the right figure in Figure 3.8.

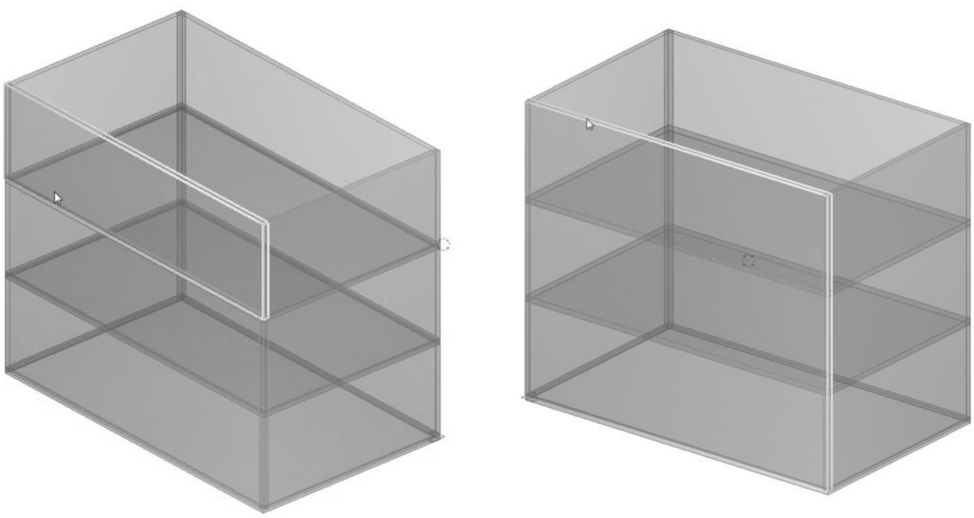

Figure 3.8 To the right: a model with three panels upon each other, one top panel is highlighted. To the left: A model with one panel spanned all the way from the bottom to the top. The entire panel is highlighted.

The two models were separately exported to SAP2000 and boundary conditions were assigned to the edges of the bottom slab. A surface load was applied to the top slab and the model was analysed.

Result

The models, independent of used modelling method, were exported to SAP. The panels modelled as separate areas were exported as separate areas to SAP, and the same correct export was for the panel modelled as one entire area which was exported as one area to SAP, see Figure 3.9.

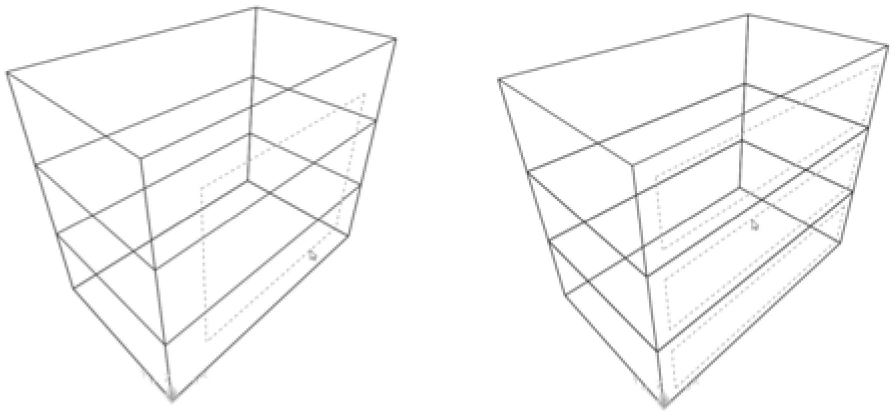

Figure 3.9 To the right: a model with three panels upon each other, one top panel is highlighted, exported to SAP. To the left: A model with one panel spanned all the way from the bottom to the top. The entire panel is highlighted, exported to SAP.

Stresses from the analysis from respective modelling were compared between the models and it was seen that the response of the models was approximately the same for both models.

Conclusion

The method of modelling for several panel and slab elements in connection to each other does not influence the result of the export.

Recommendations

- Since both modelling techniques are giving the same result it is recommended to use the modelling method most suited for the situation.

3.3 Export of openings in panel and slab elements

A structure generally consists of irregularities such as windows and doors which are modelled as openings in TS. There are a few different techniques to model openings in TS. The purpose of this study is to identify feasibilities and limitations of the export from TS to SAP of panels and slabs containing openings.

The sub-study is divided into seven studies:

- Export of rectangular openings within a panel element
- Export of several panel elements creating an opening
- Export of rectangular openings at the edge of a panel element
- Export of panel and slab elements with rectangular openings
- Export of a circular opening within a panel element
- Export of a circular opening at the edge of a panel element
- Export of rectangular openings in a slab element

3.3.1 Export of rectangular openings within a panel element

Purpose

The purpose of the export was to examine if rectangular openings, see Figure 3.10, modelled with different modelling techniques within a panel were exported.

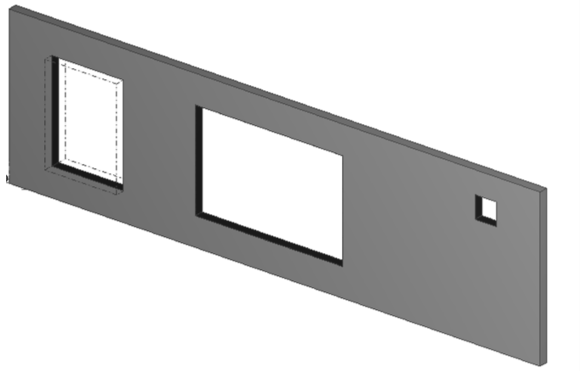

Figure 3.10 Openings modelled within a panel in TS using different modelling techniques.

Approach

Openings were created in the panel, see Figure 3.11, using the following modelling techniques:

a) Cut part with another part.
b) Cut part with polygon.
c) Cut part with component (*Hole generation*).

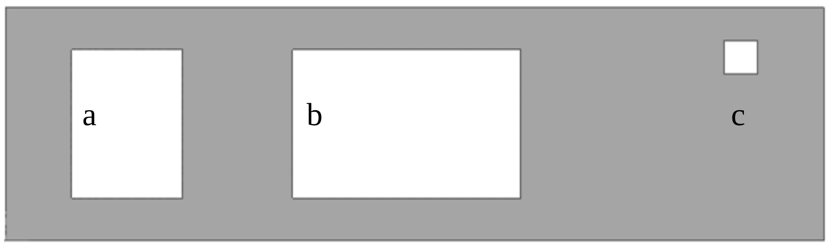

Figure 3.11 Openings in a panel element modelled with different modelling techniques.

Result

It was observed that nodes and analysis lines were created for each opening see Figure 3.12.

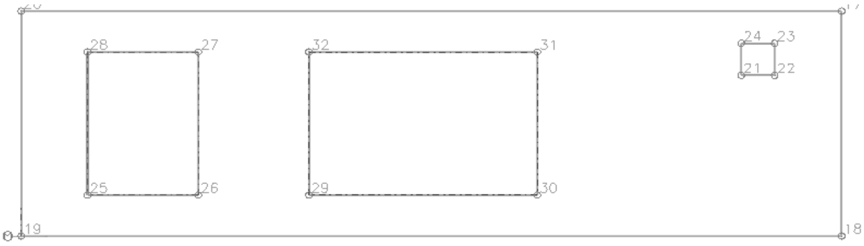

Figure 3.12 The analysis lines and node numbering generated for the model in TS.

Although analysis lines were created for the openings they were not exported from TS to SAP, no matter used modelling technique. However, the nodes of each opening were exported and displayed in SAP. The numbering of each node in TS corresponds to the same number in SAP, compare Figure 3.12 and Figure 3.13.

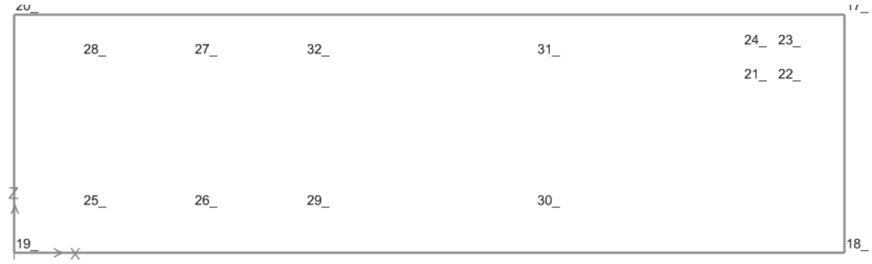

Figure 3.13 The symmetry line and node numbering generated for the model in SAP.

The fact that the nodes were exported from TS to SAP made it possible to create the openings in SAP again in order to perform an analysis. This was done by divide the element and erase parts constitutes the opening.

When dividing areas the meshing option *No automatic Mesh* is automatic chosen by SAP and the user needs to specify the wanted mesh. The mesh option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* with a check at the *sub mesh option* gave an accepted mesh.

Conclusion

Rectangular openings modelled in a panel in TS are not exported to SAP, however the created nodes of each opening are exported and can be displayed in SAP. It is possible to create the opening in SAP again with the help of the exported nodes.

Recommendations

- It is recommended to model the openings in TS to make the work of the structural engineer easier. The openings can then be created in SAP by the *Divide Area Using Cookie Cut Based On Selected Point Objects.*
- It is recommended to use the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)*. In order to generate a finer mesh the choice of choosing a *maximum size* of the mesh-elements can be used by the *sub mesh option*.

3.3.2 Export of several panel elements creating an opening

Purpose

The purpose of the export was to examine if a rectangular opening, formed by modelling several panels creating the opening were exported, see Figure 3.14

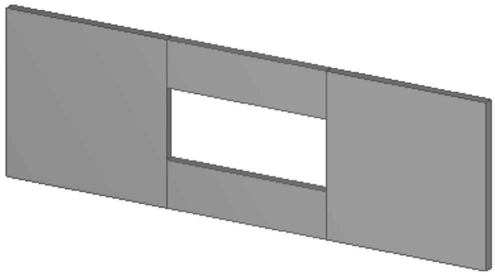

Figure 3.14 Several panels modelled to create an opening in the model.

Approach

The model was created using *concrete panel*-tool. The panels were placed so that an opening was formed within the wall, see Figure 3.15.

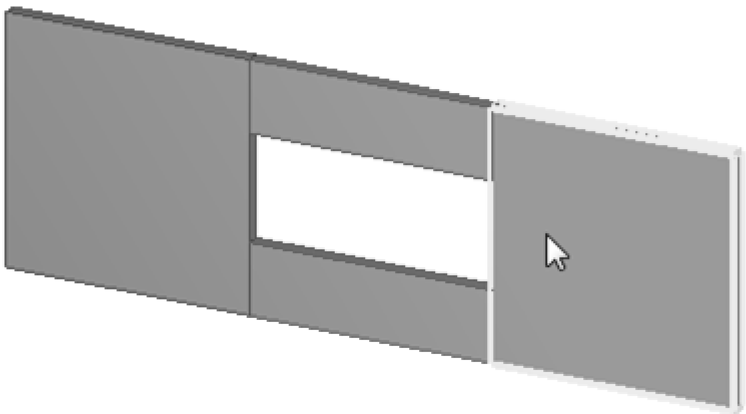

Figure 3.15 Panels modelled to create an opening in the middle of the model.

Result

The *Analysis & Design model* was created in TS and it was observed that nodes and connected analysis line were created for each panel, see Figure 3.16.

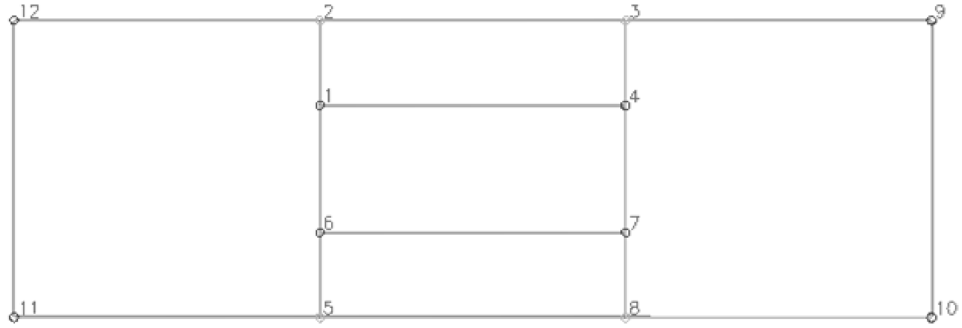

Figure 3.16 The analysis- and design model in TS for panels modelled to create an

The panel elements were exported to SAP as connected elements forming an opening, see Figure 3.17.

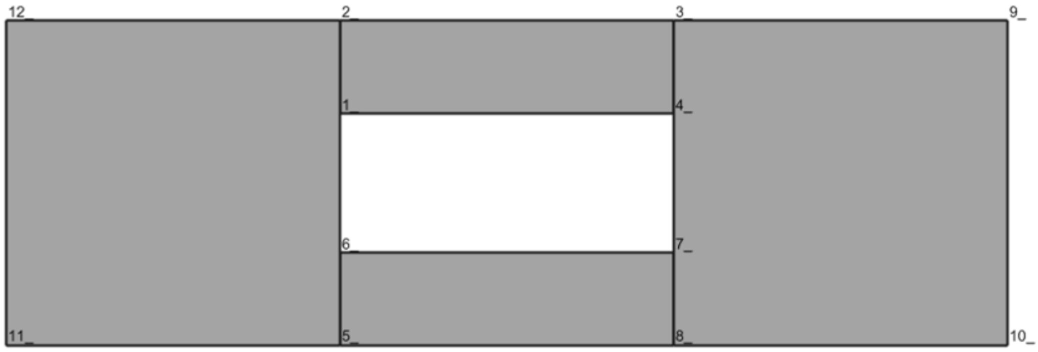

Figure 3.17 The exported model in SAP with a created opening in the model.

Unlike the other panels containing openings, the program chosen mesh option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* with a check at the *sub mesh option* gave an accepted mesh.

Conclusions

An opening created by modelling several panels around leaving an opening is exported to SAP without any further modifications.

Recommendations

- The mesh option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* generated by SAP is recommended to be used. In order to generate a finer mesh the choice of choosing a *maximum size* of the mesh-elements can be used by the *sub mesh option*.

3.3.3 Export of rectangular openings at the edge of a panel element

Purpose

The purpose of the export was to examine if rectangular openings, see Figure 3.18, modelled with different modelling techniques at the edge of a panel were exported.

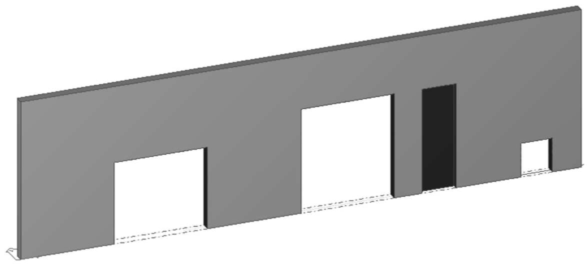

Figure 3.18 The model in TS with rectangular openings at the edge of a panel.

Approach

Openings were created in the panel, see Figure 3.19, using the following modelling techniques:

a) Cut part with line (shortening of the panel).
b) Cut part with polygon.
c) Cut part with another part.
d) Cut part with another part – a partly cut out.
e) Cut part with component (*Hole generation*).

Comment: *Partly cut out* can be described as an element which is not totally cut through, only a part is cut out.

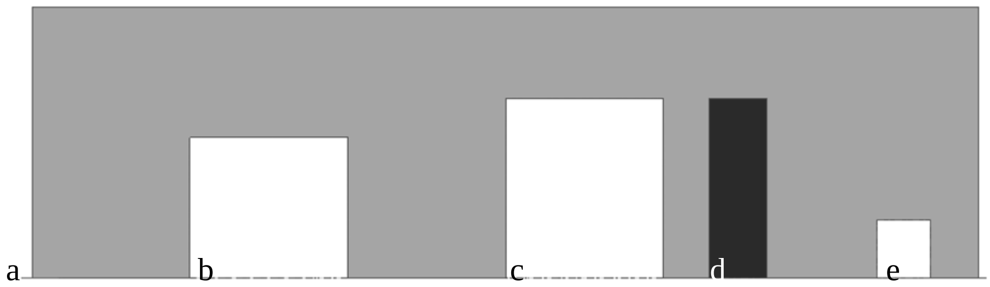

Figure 3.19 Openings modelled in a panel in TS, created with different modelling techniques.

Result

It was observed that nodes and connected analysis lines were created for the panel and the openings, including the *Cut part with line* at the end. The part which was only *partly cut out* was not assigned any analysis line or nodes, see Figure 3.20.

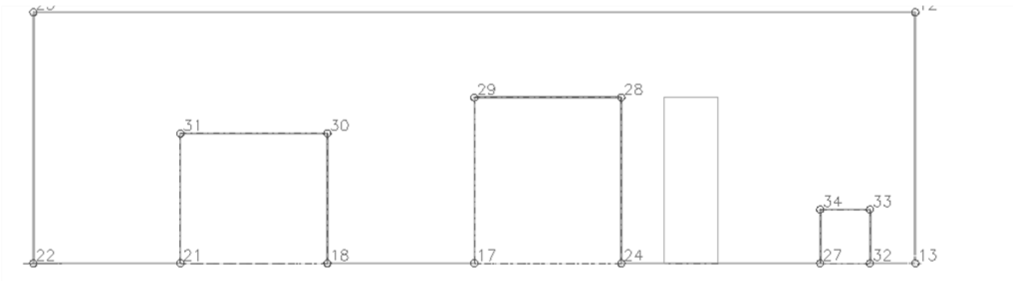

Figure 3.20 The created analysis line in TS for the model containing openings at the edge of a panel.

The panel and openings were exported to SAP, except for the part which was only *partly cut out* for which no analysis line was created. The shortening of the wall modelled with *cut part with line* was exported see Figure 3.21. The option *Divide Area Using Cookie Cut Based On Selected Point Objects* together with *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* gave an accepted mesh.

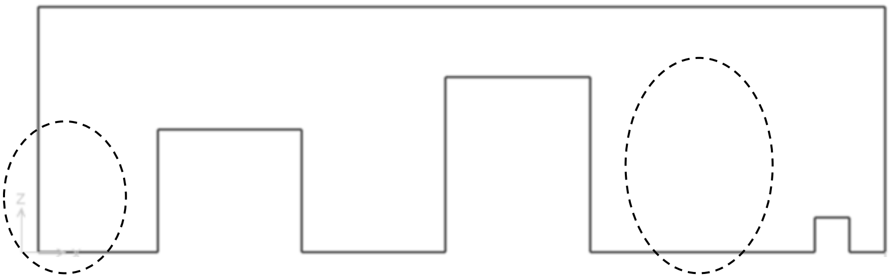

Figure 3.21 The exported model in SAP with the partly cut out is not displayed.

Conclusion

Rectangular openings modelled at the edge of a panel in TS were exported to SAP, except for the part which was only *partly cut out* openings which was not exported.

Recommendations

- It is recommended to use the divide option *Divide Area Using Cookie Cut Based On Selected Point Objects* together with *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* for an element containing rectangular openings. In order to generate a finer mesh the choice of choosing a *maximum size* of the mesh-elements can be used by the *sub mesh option*.
- Parts which is only p*artly cut out* created with the tool *cut part with another part* is not recommended to be used in the export between TS and SAP.

3.3.4 Export of panel and slab elements with rectangular openings

Purpose

The purpose of the export was to examine if opening within a model consisting of several connected panels and slabs, see Figure 3.22, manually can be created in SAP.

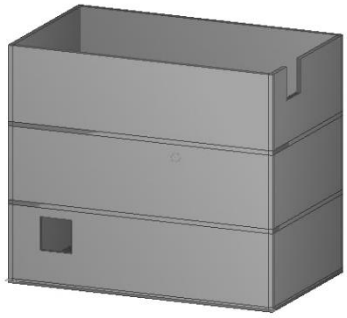

Figure 3.22 A model of several connected panel and slab elements containing openings

Approach

Openings were created in the panel, see Figure 3.23, using *Cut part with component* (*Hole generation*).

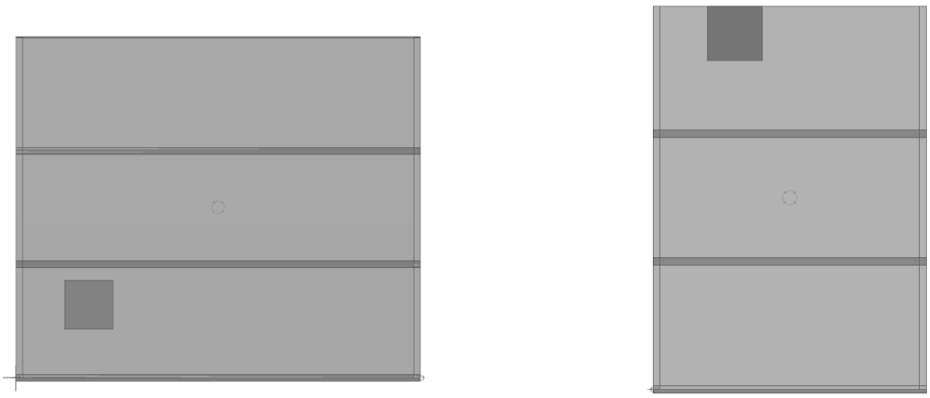

Figure 3.23 Openings modelled within the panels and at the edge of a panel.

Result

When creating the *Analysis & Design model* it was observed that connected analysis lines were created for the panel with opening at the edge, while only nodes were created for the opening within the panel, see Figure 3.24.

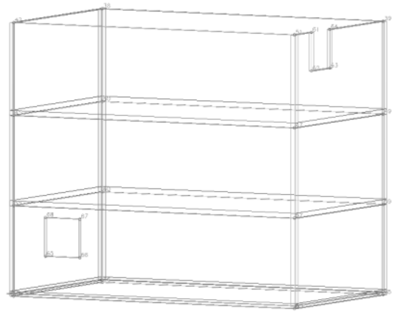

Figure 3.24 Created Analysis & Design model in TS for several panels containing opening.

As expected was the opening at the edge exported while only the nodes of the opening modelled within the panel were exported, see Figure 3.25.

The model was divided into smaller areas and the opening could be created. The meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* gave an accepted mesh.

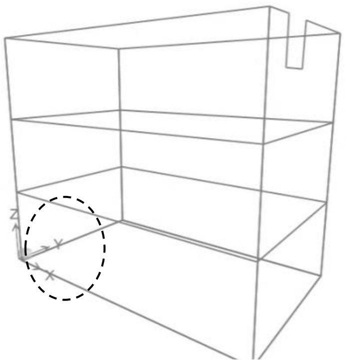

Figure 3.25 The exported model in SAP for several panels containing openings.

Conclusion

In a more complex model consisting of several panel and slab elements it is possible to manually create an opening in SAP.

Recommendations

- It is recommended to first divide the model with *Divide Area Using Cookie Cut Based On Selected Point Objects* continued by use the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* for connected model containing rectangular openings. In order to generate a finer mesh the choice of choosing a *maximum size* of the mesh-elements can be used by the *sub mesh option*.

3.3.5 Export of a circular opening within a panel element

Purpose

The purpose of the export was to examine if circular openings modelled within a panel were exported, see Figure 3.26.

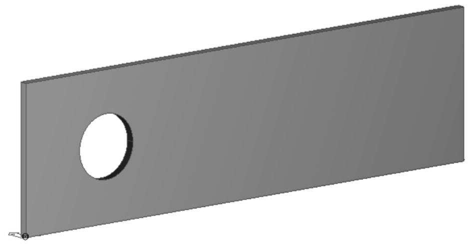

Figure 3.26 A panel modelled in TS with a circular opening within the panel.

Approach

The circular opening in the panel was modelled by using the modelling technique *Hole generation*.

Result

When creating the *Analysis & Design model* it was observed that nodes and analysis lines were created for the panel and for the circular opening, see Figure 3.27.

Figure 3.27 The analysis model created in TS for the panel with a circular opening.

Although an analysis line was created for the opening it was not exported, however, the nodes of the opening were exported, see Figure 3.28.

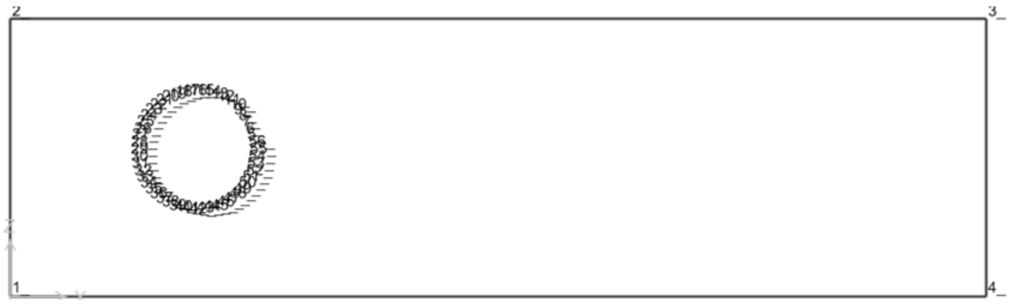

Figure 3.28 The analysis model created in SAP for the panel with a circular opening.

It was possible to create the circular opening in SAP, but the method was time-consuming. Even though a circular opening could be created, it was not possible to generate an acceptable mesh for the panel containing a circular opening.

Conclusion

Circular openings modelled in a panel in TS are not exported to SAP, however the created nodes of each opening are exported and can be displayed in SAP. It is possible to create the opening in SAP, again with the help of each node, but the method is time-consuming. Since the nodes are generated to closely it is anyhow not possible to achieve an acceptable mesh for a panel element containing a circular opening.

Recommendations

- It is recommended, as far as possible, to model rectangular openings in TS instead of circular openings.

3.3.6 Export of a circular opening at the edge of a panel element

Purpose

The purpose of the export was to examine if circular openings modelled at the edge of a panel, see Figure 3.29, were exported.

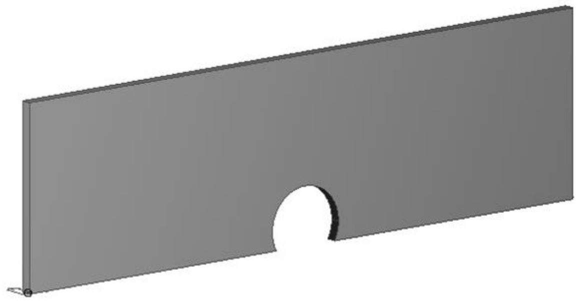

Figure 3.29 Circular opening modelled at the edge of a panel.

Approach

A circular opening at the edge of the wall was modelled by the modelling technique *Hole generation*.

Result

When creating the *Analysis & Design model* it was observed that nodes and one analysis lines were created for the model, see Figure 3.30.

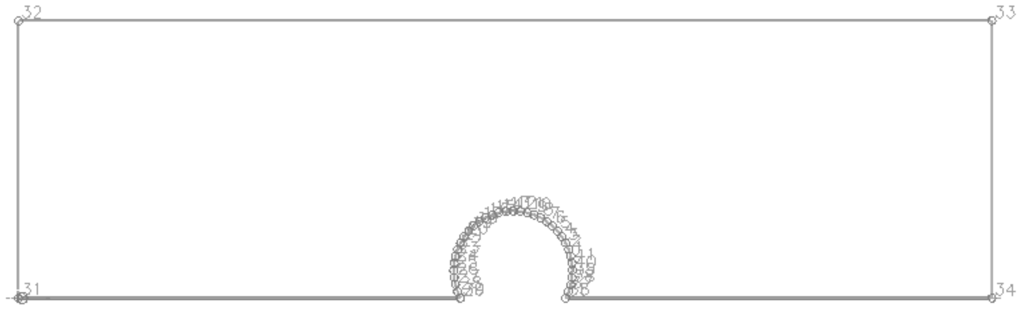

Figure 3.30 Analysis & Design model in TS for a panel element containing a circular opening at the edge.

The circular opening in the panel was exported to SAP and received the same node numbering as generated in TS, see Figure 3.31. However, it was not possible to mesh the panel containing a circular opening at the edge.

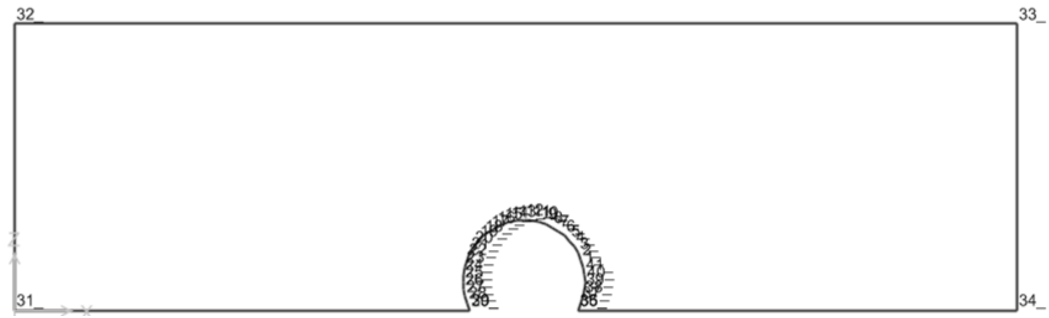

Figure 3.31 The exported model for a panel element containing a circular opening at the edge.

Conclusion

Circular openings modelled at the edge of a panel in TS are exported to SAP. Since the nodes are generated to closely it is anyhow not possible to achieve an acceptable mesh for a panel element containing a circular opening.

Recommendations

- It is recommended, as far as possible, to model rectangular openings at the edge of a panel in TS instead of circular openings.

3.3.7 Export of rectangular openings in a slab element

Purpose

The purpose of the export was to examine if rectangular openings modelled both in and at the edge of a slab, see Figure 3.32, were exported.

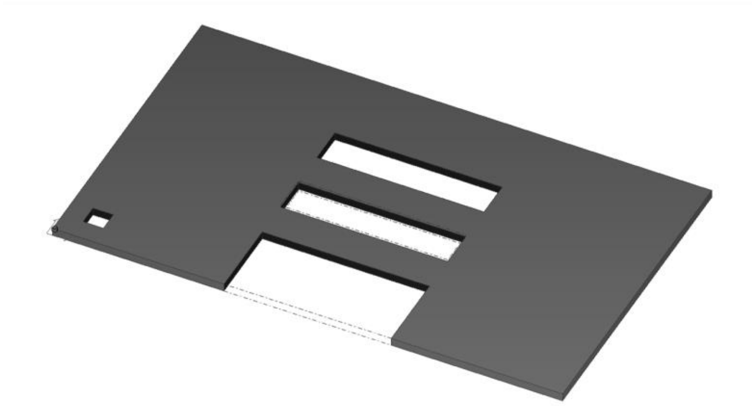

Figure 3.32 Openings within and at the edge of a slab modelled in TS.

Approach

Openings were created in the slab, see Figure 3.33, and the following modelling techniques was used:

a) Cut part with polygon.
b) Cut part with another part.
c) Cut part with another part – no opening but party cut through.
d) Cut part with component (*Hole generation*).

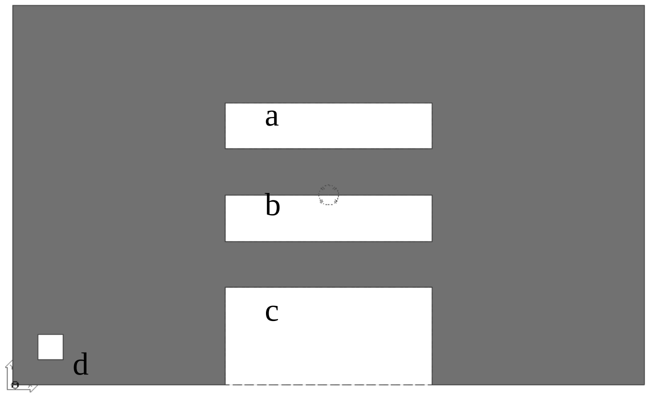

Figure 3.33 The model containing openings modelled with different techniques in TS.

Result

From the *Analysis & Design model* it was observed that the nodes and the analysis lines were created for the slab and openings, see Figure 3.34.

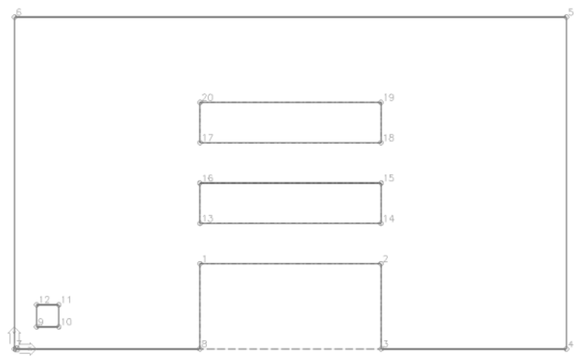

Figure 3.34 The Analysis & Design model in TS created for the model with openings within and at the edge of the slab in TS.

The result of the export of slab with openings was similar to the export of the panel with openings. The openings at the edge of the slab were exported while for the openings within the slab only the nodes were exported, see Figure 3.35. These openings could be modelled in SAP with the help of the exported nodes.

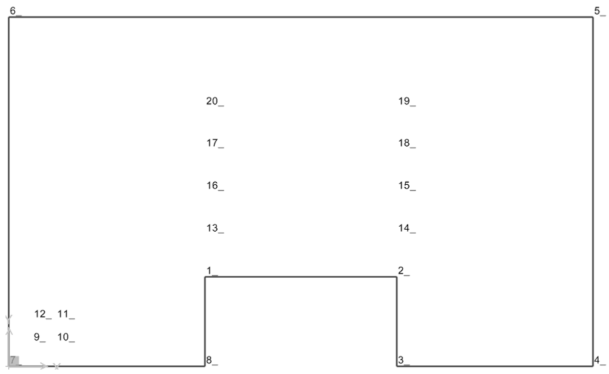

Figure 3.35 The exported model in SAP of the model containing openings within and at the edge of the slab.

> **Conclusion**
>
> The result of the export for openings within and at the edge of a slab is similar to the result generated for the export of openings in and at the edge of a panel.

> **Recommendations**
>
> - The recommendations for the export of openings in and at the edge of a slab are the same as those given for a slab containing openings.

3.4 Export of connected panel, slab, beam and column elements

A structure today usually consists of panels and slabs modelled in connection to beams and column elements. The purpose of this study is to identify feasibilities and limitations of the export between TS and SAP of panel and slab elements modelled in connection to a column element.

The sub-study is described only by one export.

- Export of connected slab and column elements

3.4.1 Export of connected slab and column elements

Purpose

The purpose of the export was to examine if slabs modelled in connection to a column, see Figure 3.36, were exported as connected elements.

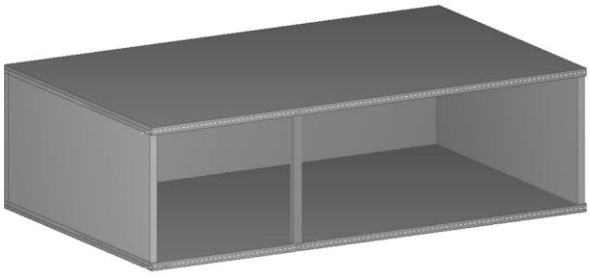

Figure 3.36 The structure in TS containing panels and a column connected to the slabs.

Approach

The panels were modelled with *concrete panel*-tool and the column with *concrete column*-tool. The panels were modelled between two slabs and the column was placed at the edge between the slabs. The structure was analysed with the influence of dead weight.

Result

The *Analysis & Design model* was created with connected analysis lines, see Figure 3.37.

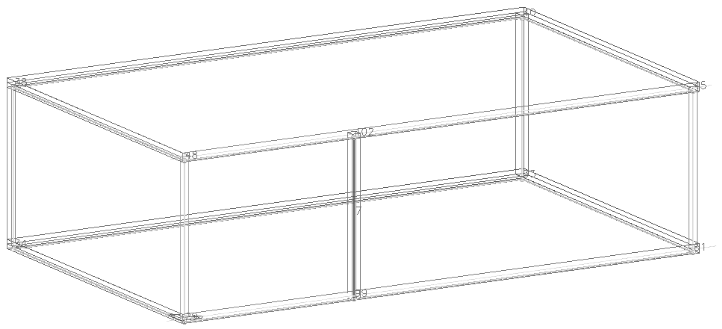

Figure 3.37 The Analysis & Design model in TS for the model with panels, slabs and a column.

An analysis in SAP showed that the model was exported as one connected structure with the column connected to the both slabs, see Figure 3.38.

The mesh option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* which gave an accepted mesh after first dividing the slab.

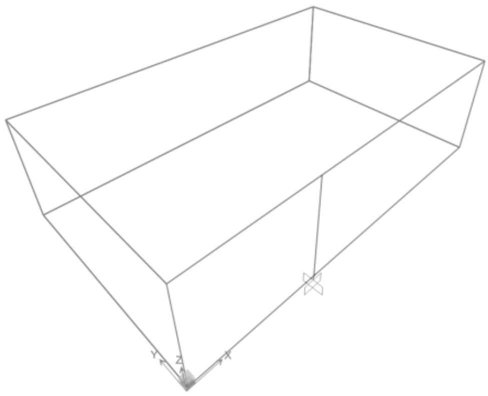

Figure 3.38 The model with panels and slabs in connection to a column, exported to SAP.

Conclusion

Slabs in connection to a column are exported as connected from TS to SAP.

Recommendations

- It is recommended to use the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)* with a check at the *sub mesh option.* In order to generate a finer mesh the choice of choosing a *maximum size* of the mesh-elements can be used by the *sub mesh option*.

3.5 Results of the case study

This chapter includes a summary of results from the case study described by feasibilities and limitations followed by answers to the studied questions. Final recommendations for the export and suggested further improvements are as well presented.

3.5.1 Summary of feasibilities and limitations

Single and connected panel, slab, beam and column elements and information attached to the elements were exported from TS to SAP. Modelled connected elements were exported to SAP as connected elements if they shared analysis lines in the *Analysis & Design model*.

Rectangular and circular openings within a panel or a slab were not exported. However, nodes of each opening were transferred. It was possible to create the openings in SAP using the exported nodes, but for circular openings this work was considered to be very time-consuming. Positively, rectangular and circular openings at the edge of a panel or a slab were exported. A panel or slab containing rectangular openings could be meshed, while it was not possible to mesh an element containing circular openings.

Feasibilities for the export

- Single panel, slab, beam and column elements are exported.
- Several panel and slab elements are exported as connected elements, if they share analysis lines in TS.
- Information connected to panel and slab elements are exported
- The global orientation of a model is exported.
- Non-exported openings can manually be created in SAP.
- Openings modeled at the edge of a panel in TS are exported to SAP.
- Openings modeled by separate panels forming an opening are directly exported.

Limitations for the export

- Openings modeled within panel or slab elements are not exported to SAP.
- Parts which are only p*artly cut out* are not exported.
- The method of recreating circular openings in SAP of openings which are not exported is time-consuming.
- It is not possible to mesh an element containing circular openings.

3.5.2 Answers to studied questions

The questions stated in chapter 3.1.1 are answered in this chapter.

How should a single surface, a panel or a slab element, be modelled in order to enable an export from TS to SAP?
The modelling technique of a panel and or slab does not affect the export from TS to SAP i.e. a surface can be modelled in any possible way in order to enable an export.

How should connected elements be modelled in TS in order to generate a connected model in SAP?
Elements should be placed within a distance of tolerance pre-defined in TS in order to generate shared analysis lines and one *Analysis & Design model*. If the elements are modelled connecting in their centre lines a common analysis line is created. However, if analysis lines are not connecting, this could be adjusted by manually moving the lines.

How should openings be modelled in panel and slab elements in TS in order to be exported to SAP?
Openings at the edge of a panel or slab can be modelled by any modelling technique. They are exported independent of used modelling technique. However, openings within a panel or slab are only exported if the opening is created by several panel or slab elements forming the opening. Openings created, within a panel or slab, by modelling techniques available in TS results in non-exported openings. But, worth mentioning is the possibility of creating these openings in SAP. The openings can manually be recreated in SAP by dividing the model into smaller elements based on all nodes. Thereafter, the area that constitutes the opening can be erased. For rectangular openings this is a feasible method but for circular openings this method is considered to be time-consuming.

3.6 Discussion of results

This chapter includes a discussion concerning the result of the case study. Further discussion regarding compatible software in a more general perspective is presented in chapter 4.

The case study focused on export from Tekla Structures to SAP2000 using the compatible link *Export*. It was relatively easy to create an *Analysis & Design model* in TS and export it to SAP were it could be analysed. However, some failures in the export were encountered which need to be discussed further in order to draw conclusions about the compatibility of TS and SAP and to give recommendations to optimise the use.

In order to export connected elements it was mentioned how the analysis lines in between the elements must be shared. To manage shared analysis lines the elements must be placed within a distance of tolerance or by manually moving the analysis lines after the creation of the *Analysis & Design model*. The tolerance limit is not known for the user and is neither possible to change. By making this available and changeable, both time and money could be saved in the working process.

Further on, rectangular and circular openings modelled within a panel or slab using corresponding modelling techniques in TS are not exported to SAP. This is a huge drawback for the use of the compatible link since most structures includes openings illustrating for example windows, installations etc. It was described how the analysis lines in TS are translated to symmetry lines in SAP. The openings were correctly defined by analysis lines with associated nodes in the *Analysis & Design model*. Although, the analysis lines were not translated to symmetry lines in SAP. However, the nodes associated with the openings were exported. Worth mentioning in this context is the fact that openings at the edge are perfectly exported from TS to SAP. Considering the result of this study, the failure can either depend on deficiencies in the compatible link or simply that element containing opening is not supported by SAP. The last case may explain the fact that openings at the edge are exported. The created analysis lines of the openings at the edge of an element are directly connected to the analysis lines of the entire panel or slab.

In order to overcome this drawback some possible solutions may be used. A first possible solution may be to model openings in TS and export the model to SAP. The openings will then manually be created in SAP again, provided that the CAD-technician informs the structural engineer were to find the nodes defining the openings. This method is time-consuming for the structural engineer. A second possible solution is to create the opening in TS by modelling panels around it, i.e. panels are modelled forming an opening. This makes the work instead more time-consuming for the CAD-technician. In conclusion, the fact that openings may be created by either the CAD-technician or the structural engineer raises the question of work division and responsibility. Further on, it also influence the way of communicating. These questions are further discussed in chapter 4.

Concerning the performance of an analysis the choice of relevant mesh is important for the outcome of the analysis. During the case study, recommendations were continuously given concerning acceptable mesh options. However, the choice of mesh highly depends on the wanted results which make it hard to give a general recommendation for the choice of mesh. This fact must be taken into consideration when using the given recommendations in this thesis.

A limitation in the investigation was that the study only included the export from TS to SAP. The export from SAP to TS was not investigated since it was not relevant due to the lack of possibility in designing concrete panels or slabs in SAP. This can instead preferable be performed by other software using the results from the analysis in SAP. The limitation of investigating one way transfer affects the outcome, since the results from the case study do not cover the total design process and neither gives the entire picture of the compatibility of TS and SAP.

Overall, the outcome of the case study indicated how compatible software can be used in general, and how the work of the CAD-technician and the structural engineer can be divided. One conclusion is that the deficiencies in the export between TS and SAP mostly seem to depend on the ability of each individual software, i.e. not the compatible link. Some suggested improvements are mentioned in chapter 3.8. However, despite the inadequacy in the export the compatible software may in fact reduce the need of double or remodelling and thereby be able to facilitate an integrated working process.

3.7 Recommendations for the export

Outcome of the case study resulted, together with the discussion, in a number of recommendations for optimising the use of the compatible link between Tekla Structures and SAP2000. The recommendations form, along with instructions, a manual for the usage of the *Export*-link. The manual is presented in Appendix II.

General

- It is recommended to check the *warning counts* that might appear during creation of the *Analysis & design model*.
- It is recommended to check the *warnings/errors* that might appear during the export of the model.

Elements without openings

- For panels and slabs <u>without</u> openings it is recommended to use the mesh option chosen by the program.

Elements with openings

- It is recommended to model rectangular openings within elements in TS even though they are not exported.
- The not exported openings are recommended to be created using the dividing option *Divide Area Using Cookie Cut Based On Selected Point Objects* in SAP.
- For an element containing rectangular openings, either within the element or at the edge, it is recommended to always first divide the model with *Divide Area Using Cookie Cut Based On Selected Point Objects* continued by use the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)*. The *sub mesh option* is recommended to be used if needed.
- It is recommended, as far as possible, to replace modelled circular openings with rectangular openings. Possible circular openings are recommended to be erased by the structural engineer before performing an analysis.

Panel and slab elements in connection to a line element

- It is recommended to model connected panel, slab, beam and column elements without adding any restraints in TS.
- For a model containing connected panel, slab, beam and column elements it is recommended to first divide the model with *Divide Area Using Cookie Cut Based On Selected Point Objects* continued by use the mesh option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)*. The *sub mesh option* is recommended to be used if needed.

3.8 Suggested further improvements

In order to fully utilise the use of the *Export*-link some further improvements, both for the compatible link and also for the individual software, are recommended:

- The distance of tolerance for the creation of the *Analysis & Design model* should be viewable and changeable for the user to define in TS.
- The support of elements containing openings should be improved in SAP.
- Meshing of shell elements containing circular opening should be improved.
- An export from SAP to TS should be possible for a model with manual changes performed in SAP.

4 Discussion

In this chapter a discussion is held concerning a more integrated working method in the structural design process. It includes a discussion about the importance of an integrated work and the definition of an integrated working process of the CAD-technician and the structural engineer. Further on are difficulties for a more integrated working method identified and discussed and finally are feasible solutions in order to manage the difficulties presented and discussed.

4.1 The importance of a more integrated working process

The design phase plays an important role for the quality of design of a building project. The work of the CAD-technician and the structural engineer is today mostly performed separately. During the iterative work a lot of changes must be communicated between the actors and information can easily be lost in between. It is also ineffective to create two similar but separated models, where each model must be updated to the continuously performed changes. This makes the need of a well working integrated working method even larger. An increased integrated working method would, as mentioned in chapter 2.5, generate benefits for the outcome not possible for each individual actor to generate. In this sense, an integrated working process may be described as involved actors working together instead of separate towards a common solution.

The CAD-technician and the structural engineer can benefit from an increased integrated work in a lot of ways. Mainly, through a more integrated working method a more effective and productively work is accomplished which results in saving time and money. Further on, it may result in a reduction of lost information between the actors and an increased utilisation of available information which will both improve the outcome of the work. The related benefits are presented in the following illustration, see Figure 4.1.

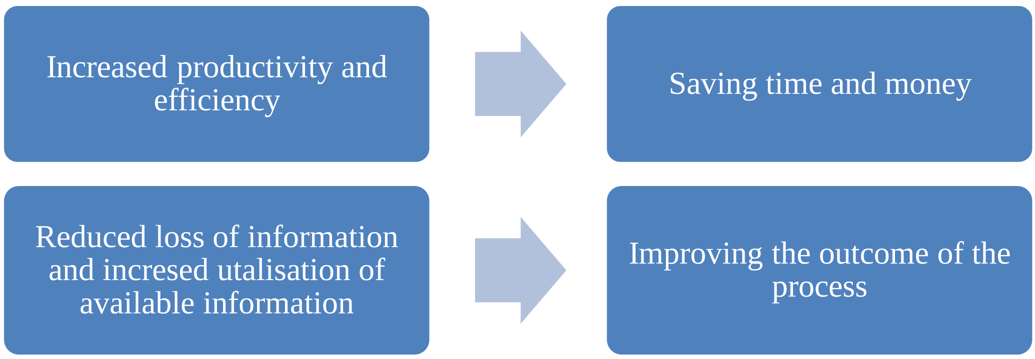

Figure 4.1 The main benefits of an increased integrated working method.

In order to work together towards a common solution, it is obvious that communication between the actors is required. It is described in chapter 2.6 how it today seems logical to communicate through computers thanks to the development of technology. The increased use of computers enables for an automation of communication by an electronic exchange of information, which can result in reduced unnecessary effort and human errors. However, automatic electronic exchange cannot by itself draw conclusions about results. Neither does it cover the total information exchange needed. This makes manual communication, in addition to the automatic communication, necessary to enable a more integrated working process.

Moreover, the development of technical tools has resulted in that computer-based technical tools today are essential for the separated work of the CAD-technician and the structural engineer. The fact that computer-based technical tools are necessary creates the conclusion that an integration of these is of high importance in order to increase the integrated work. In chapter 2.7 it was described how compatible software has the possibility to facilitate for a more integrated working method. By using compatible software it is possible to create one model which can be used both by the CAD-technician and the structural engineer. The need of remodelling and duplicated work is by that decreased and time and money are two major factors that could be saved.

To summarise, an integrated working method of the CAD-technician and the structural engineer in the design phase is described in terms of manual communication and compatible technical tools.

4.2 Difficulties in an integrated working process

In the context of an increased integrated work of the CAD-technician and the structural engineer some identified difficulties must be discussed.

The necessity of manual communication was underlined in chapter 4.1. However, in literature this way of communicating is described to be ineffective, costly and changes are easily missed to be communicated. The fact that manual communication is a necessary complement to automatic communication makes the deficiencies associated with manual communication important to solve.

The most important advantage possible to utilise by using compatible software is the use of one common model in the work of both the CAD-technician and the structural engineer. An important difficulty is the differences in purpose and thus the defined geometries of the two models. As prior described, the purpose of the model created by the CAD-technician is to create drawings, i.e. fully described geometries, while the purpose of the model created by the structural engineer is to analyse and design the structure, i.e. simplified and idealised geometries. An additional difficulty for the compatible solution Tekla Structures and SAP2000 is the fact that the two compatible software must be installed on the same computer in order to use the compatible link. The two actors are, as a limitation in this project, assumed to be represented by different persons and thus two computers are used. This will limit the use of the compatible link to a great extent because of an increased need of software licenses which will make the process more costly.

Moreover, a general drawback encountered during the case study was the lack of information and instructions supporting the compatible link. Moreover, some deficiencies in the export were discovered that are highly important to overcome. One example of such deficiency was the failure in exporting openings within a panel or a slab which was further discussed in chapter 3.5.

Further on, an integrated working process creates a shared work space. It is defined as the space where both actors can operate. A shared working space may result in large advantages for an integrated working process. One large advantage is the fact that the flexibility in design may be increased since the work could be performed both by the CAD-technician and by the structural engineer. Consequently, the work does no longer depend on the work of only one actor, instead a more integrated work with lager possibilities of flexibility could be utilised. This could as well generate a more open design phase with larger possibilities of an increased integrated design for all actors involved in the project. However, a shared work space changes the fact that previous clear roles are no longer that clear. The division of work may be changed and in turn as well the responsibility of each actor will be different. This may result in conflicts, ineffective work and incorrect results.

Another difficulty related to an increased integrated working method is more associated with attitudes. The building sector apprehends to be conservative and changes can often be hard to implement. Based on the impressions gained during the project each individual actor only sees his own work and actors sometimes have no will to compromise.

By identifying and discussing these changes and difficulties the question to ask is if the working method of the CAD-technician and the structural engineer actually can be more integrated.

4.3 Feasible solutions to manage important difficulties

In order to reach benefits created with a more integrated work of the CAD-technician and the structural engineer, feasible solutions must be found to manage the identified changes and difficulties.

A clear understanding of how the information should be exchanged between the actors may solve many issues related to communication failures. Further on, the development of automatic communication may reduce the need of manual communication but today manual communication still is an essential part in an integrated working process. Manual communication is, as mentioned, related to some deficiencies and automatic information exchange between computers cannot today communicate all information that has to be communicated. Therefore a solution must be to not exclude any way of communicating, but instead utilise the benefits of each alternative. Information exchange between computers cannot replace the manual communication, but must act together with manual communication in order to facilitate an increased integrated working process. A recommendation for future work is thus to explore manual communication and develop manual communication alongside with the more natural development of automatic electronic exchange.

In order to utilise compatible software and results from the use of one common model the solution must be to manage the differences in purposes of the two models. A way to overcome the differences is to use the concept of linking knowledge, described in chapter 2.6. The CAD-technician must be able to create a model that both constitute a base for drawings and a base for the analysis and design. In order to manage this, the CAD-technician must hold basic knowledge in the analysis and design process, i.e. outside his particular working area. Vice versa applies for the structural engineer that needs to be aware of the working procedure of the CAD-technician. Moreover, linking knowledge is also a solution to the fact that many changes are missed to be communicated. Each individual actor must be aware of changes that will affect both their and other actors' work, in order to generate a good result.

The fact that the used software must be installed on the same computer in order to utilise the compatible link is a large problem for the compatible solution Tekla Structures and SAP2000. The most obvious working process must be for the CAD-technician to create the model and then transfer it to the computer of the structural engineer. The structural engineer opens the model in Tekla Structures and exports it to SAP2000 in order to perform the analysis and design. This way of using the compatible link seems to be ineffective and costly due to the fact that more licenses than usual are necessary. Another mentioned way to utilise compatible software is the use of the standardised file format (IFC). By exporting the model manually trough a compatible file format the mentioned limitation concerning an installation of both software on the same computer is eliminated. Different computers may be used and the model must only be transferred in between the computers. However, manual export between Tekla Structures and SAP2000 was recommended by Nilsson and Svennered not to be used. A recommendation for future work is therefore to explore and improve the compatibility by the use of compatible file format. With the use of standardised file format, models could be shared freely, not only for the specific solution of TS and SAP.

Further on, results from the case study can be used in order to discuss problems associated with a shared working space. Normally the application of boundary conditions are assigned to the work of the structural engineer, but with a shared working space it could instead be assigned by the CAD-technician and then be exported to the structural engineer. The benefits are described as many and in order to take advantages of this, linking knowledge are identified as a key. In order to see the possibilities of a shared working space and to reduce errors an understanding of the other actors work is essential. Furthermore, a clear defined division of work must be defined before project start to do not overstep the work of the other actor. A well working communication performed continuously is essential, but most important is a communication performed in an early stage.

It can be seen that linking knowledge is the solution to several identified difficulties and deficiencies as a result of an integrated working method. In order to increase the linking knowledge its importance must be highlighted and investments in education of involved actors in the building sector are necessary.

Finally, the question asked at the end of chapter 4.2 can be discussed based on the overall knowledge gained during this Master’s project. The question was raised whether the working method of the CAD-technician and the structural engineer actually can be more integrated. By summarising, an integrated working method comes with a large number of advantages. However, in order to benefit from these advantages solutions must be found to the identified difficulties. Feasible solutions have, in this chapter, been presented and discussed but several depend on further investigations and development in order to be fully utilised. The described solutions are already today considered to increase the integrated working method of the CAD-technician and the structural engineer. However, the attitude must be changed in the building sector. The participants have to be more able to compromise and to understand the importance of an integrated working process. In conclusion, with further investigations and improvements the working method of the CAD-technician and the structural engineer is possible to be more integrated.

5 Conclusions

In the following chapter the findings are summarised and the overall conclusions are stated. Further on, the research questions given in chapter 1.2 are answered and finally are conclusions that facilitate the integrated work of the CAD-technician and the structural engineer in the design phase summarised.

A building project is represented by a large number of actors and consists of a great amount of information to be arranged and communicated. Consequently, continuous communication of changes is required which makes the need of an integrated working method important. The structural design phase is identified as a great challenge, thus the main aim of this Master's project was to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in this phase. Important aspects were identified during the project and the master thesis focused on two important aspects, communication and linking knowledge. The advantages with a more integrated working process identified during the project can be summarised by a more effective work with the result of saving time and money. Further on, an integrated working process can reduce the loss of information which results in an improved outcome of the work.

A case study was performed treating the compatibility of Tekla Structures and SAP2000. The aim of the case study was to present feasibilities and limitations together with recommendations for the export. The case study resulted in the overall conclusion that the compatible link can be used in order to facilitate a more integrated working process in the design phase. However, in order to fully utilise the compatibility, further development of the compatible link and each individual software is recommended. It is therefore recommended, at this stage, only to use the compatible link in an early stage of a building project.

5.1 Assessment of used methods

To meet defined aim the project was divided into three parts, preliminary study, case study and discussion.

The preliminary study consisted of a literature study, dialogues with representatives from the industry and software learning. The identified literature was somehow vague and it was hard to collect relevant information. The conclusion of this may be the fact that it is an upcoming topic and it is more or less individual for each company. The lack of updated fact was complemented with dialogues with representatives from the industry. The conclusion is that in order to generate a wider understanding of today's situation an interview study should have been included in the project. Though, this was beyond time of this project.

Further, the case study generated a good understanding of the feasibilities and limitations of the compatibility of the software. Moreover, it also gave a good base to formulate recommendations for the export between TS and SAP. Overall, the outcome of the case study indicated how compatible software could be used in general and how the work of the CAD-technician and the structural engineer may be divided. The results gave as well guidance of how compatible software could be utilised, a method that could be implemented in other compatible solutions.

5.2 Answers to research questions

Why is an more integrated working method important in the structural design phase?
A more integrated working method would generate benefits not possible for each individual actor to produce.

What benefits could be generated from a more integrated work?
The main benefits of a more integrated working method are increased productivity and efficiency which will result in saving time and money. Further on, a reduced loss of information and increased utilisation of available information will result in higher quality.

What defines an integrated working method of the CAD-technician and the structural engineer?
An integrated working process can be described in terms of manual communication and compatible computer-based technical tools.

What difficulties have been identified in a more integrated working process?

- Ineffective manual communication
- Differences in purpose of the created models
- Lack of information and instructions supporting the compatible link
- Problems related to an increased shared working space
- Conservative industry with difficulties to implement changes

What feasible solutions can be found to manage the identified difficulties?
Manual information exchange must act as a complement to automatic communication between computers in order to facilitate an increased integrated working process. A recommendation for the future is thus to explore the manual communication and to develop this way of communicate alongside with the development of tools for electronic exchange. Moreover, to overcome the differences in purpose of the used models linking knowledge must be a used concept. The actors must hold basic knowledge about the work of the other actors in order to generate good results. Information and instructions must be available and the compatible link must be improved. Further on, the difficulties as a result of a shared space are also solved through the concept of linking knowledge. This will reduce oversteps and the unclear roles will get clearer. Finally, to work together towards a common solution participants needs to change the attitude and be more able to compromise.

5.3 Conclusions that facilitates an integrated work

Conclusions that facilitate the integrated work of the CAD-technician and the structural engineer were identified in the discussion in chapter 4. Recommendations for further development and investigations are here presented together with conclusions that are facilitating an integrated work of the CAD-technician and the structural engineer. It was discussed how the integrated working process could be described in terms of manual communication and compatible software. Thus, a development of these may then have the potential to facilitate an increased integrated work.

Manual communication must be used along with automatic communication based on compatible computer-tools in order to facilitate for an integrated working method. A recommendation is therefore to further develop the manual communication alongside with the development of automatic communication through electronic tools in order to be able to increase the integrated work.

Further on, integrated computer-based technical tools will facilitate for a more integrated working method. A compatible link or compatible file format could be used in order to integrate separated software. However, the compatibility must be improved and the knowledge about the compatible solutions must be increased in order to fully utilise compatible software.

Additional, linking knowledge was identified as a key to a number of identified deficiencies in an integrated work. Linking knowledge must exist in order to handle the differences in purpose of the two used models, in order to organise the work in the shared working space and to communicate changes to all affected actors. Further on, to see the possibilities of a shared working space and to reduce errors, linking knowledge is defined as essential. Moreover, a change of attitudes is needed. Involved actors must be more open for compromising and to understand the importance of working together towards a common solution. Finally and consequently, a recommendation for the industry is to highlight the importance of a high linking knowledge and to invest resources in educating involved actors.

6 References

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Appendix

APPENDIX I: Detailed presentation of implementation of the case study
APPENDIX II: Manual of the export from Tekla Structures to SAP2000

APPENDIX I and APPENDIX II are available as PDF.

Appendix I: Detailed presentation of implementation of the case study

Compatibility of Tekla Structures and SAP2000

Appendix II: Manual of the export from Tekla Structures to SAP2000

Export of panel and slab elements

Preface

Appendix II: *Manual of the export from Tekla Structures to SAP2000* is a appendix to the Master's project *Integrated work of the CAD-technician and the structural engineer*.

The master's project aims to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in the design phase. The Master's project focuses on the two important aspects communication and linking knowledge. The compatibility of Tekla Structure and SAP2000 is studied through a case study and by investigating the export of panel- and slab elements from Tekla Structures to SAP2000, feasibilities and limitations of the compatibility are obtained. Further on, a discussion of the feasibilities and limitaions are resulting in recommendations for the export.

The purpose of the case study was to examine the compatible link between Tekla Structures and SAP2000 through studies treating the export of panel and slab elements, openings in such elements and panel and slab elements connected to beam and column elements. A well working communication between the programs is of high importance in order to enable better coordination and integrated working method in the deisgn phase. Through the investigation of the compatibility of the software the ability of a more integrated work between the CAD-technician and the Structural engineer was studied. The result of the case study is presented as feasibilities and limitaitons for the export. Finally, the two aspects and the deeper investigated compatible software are together discussed in order to generate conclusions that facilitate a more integrated work of the CAD-technician and the structural engineer in the design phase.

The appendix aims to give a desription, step by step, of how panel and slab elements, openings in elements and panel and slab elements connected to beam and column elements can be transferred from TS to SAP. The appendix is composed from detailed printscreen pictures with a describing text. The manual is supposed to be easy to follow in order to a direct use by representavies from the industry.

In the appendix two shortnotations are used:

TS – Tekla Structures
SAP – SAP2000

Gothenburg june 2013
Lisa Beckman
Gabriella Milveden

Contents

1 Introduction

Appendix II: *Manual of the export from Tekla Structures to SAP2000* is a result from the master's project *Integrated work of the CAD-technician and the structural engineer*. The aim of the manual is to contribute to the integrated work in the design phase.

The manual describes the export of a specific model from Tekla Structure to SAP2000 with the help of the *Export* function. The export is described step by step and consists of figures and related explanations. Further on, important information and recommendations are highlighted and given continuously. The manual treats the export of panels and slabs. To read instructions about the export of columns and beams, see Appendix I related to the bachelor thesis "*Integrerad arbetsprocess mellan projektör och konstruktör*" by Nilsson and Svennered.

The manual treats the export of the following parts:

- Several connected panel and slab elements
- Openings within a panel or slab element
- Openings at the edge of a panel or slab element
- A column element connected to slab elements

Other observations from the master's project concerning the export, which are not described with the model, are presented in a final section in the end of the manual.

The model used in the manual can be seen in

Figure 1.

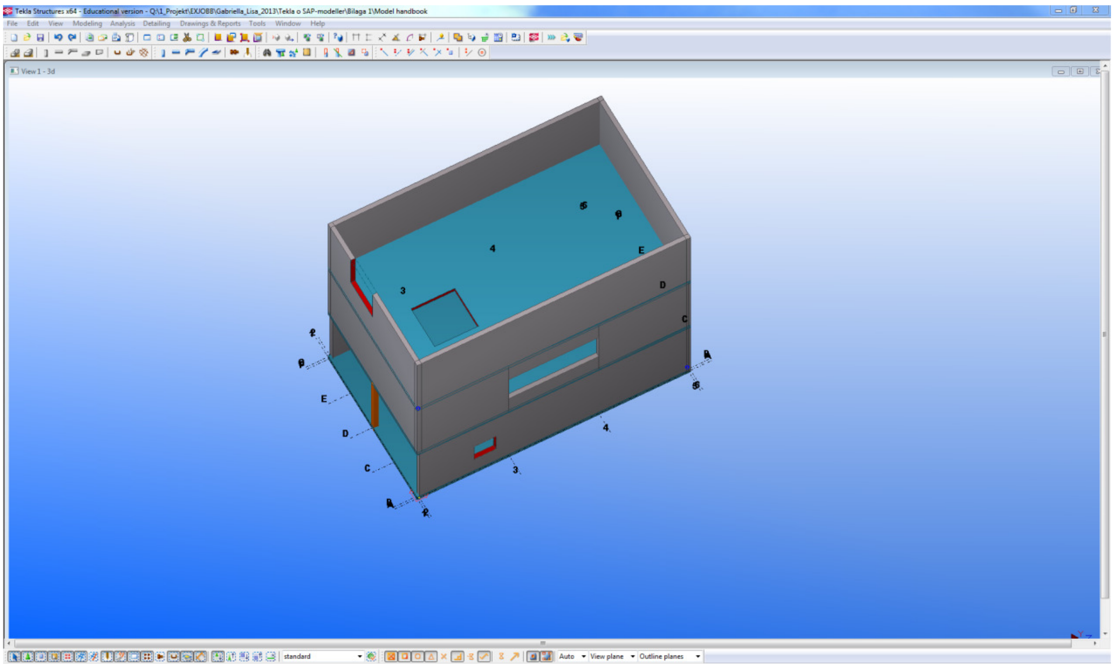


Figure 1. The used structure modeled in TS.

1.1 Conditions

In order for the manual to be useful the user needs to accomplish following conditions before usage.

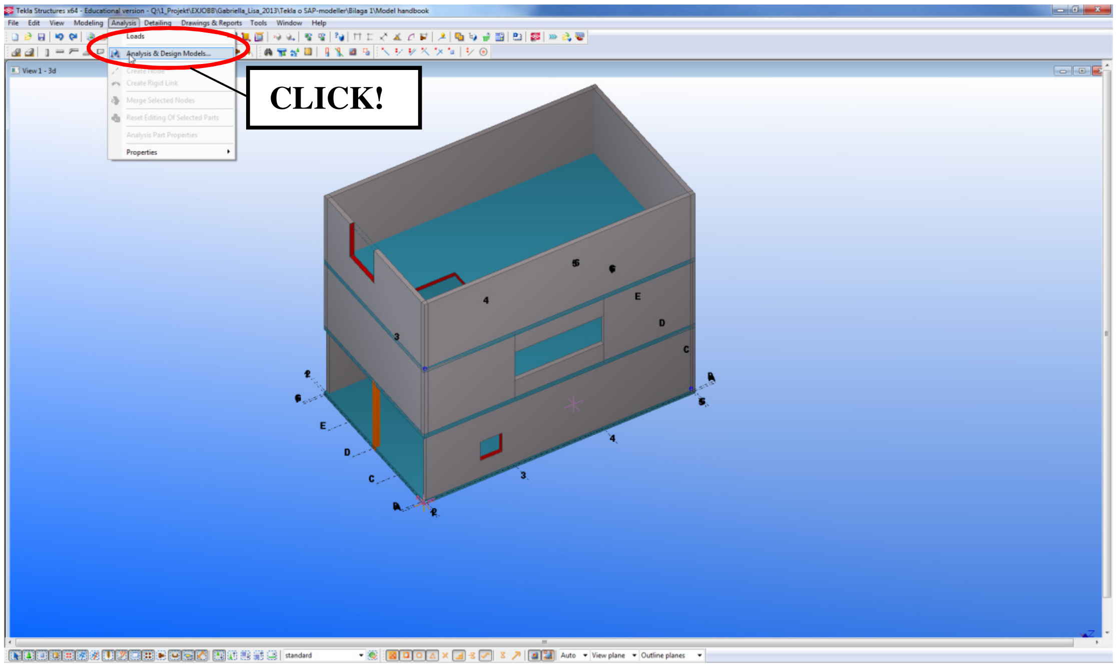
- Tekla Structures and SAP2000 needs to be installed on the same computer.
- The *Export*-link needs to be downloaded from Tekla Extranet and installed on the used computer.

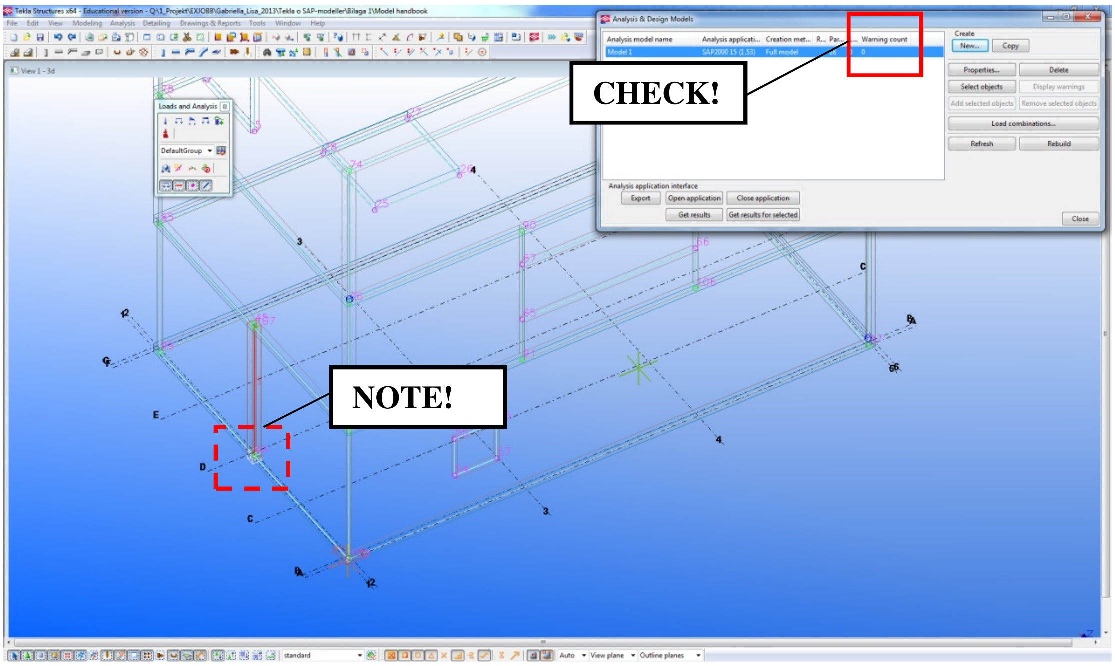
For further background and conditions for the case study refers to the master's project *Integrated work of the CAD-technician and the structural engineer*, Chapter 3 "Case study: Compatible link between software".

1.2 Modelling method

- Material properties and thickness are assigned to the elements.
- The following modelling techniques are used for creating the model: *concrete panel*, *concrete slab* and *concrete beam*.
- The model is created with elements connected in the centre line.
- The following modelling techniques are used for creating openings in the model: *Cut part with component ("Hole generation 32"), cut part with polygon* and panels modelled forming an opening.

1.3 Instructions for the layout



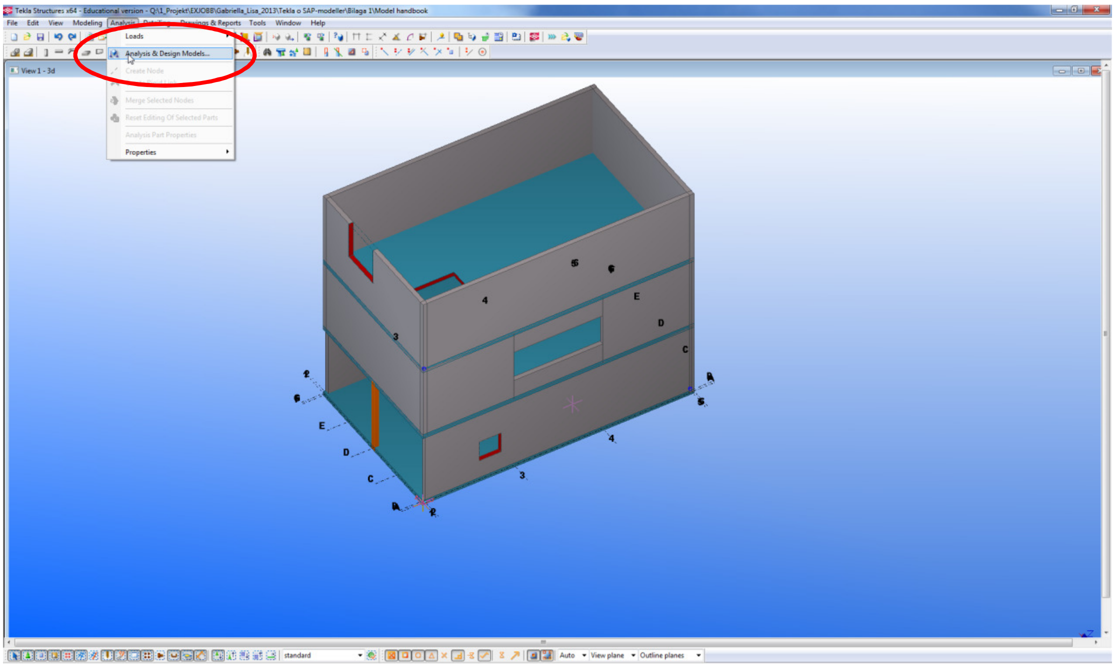


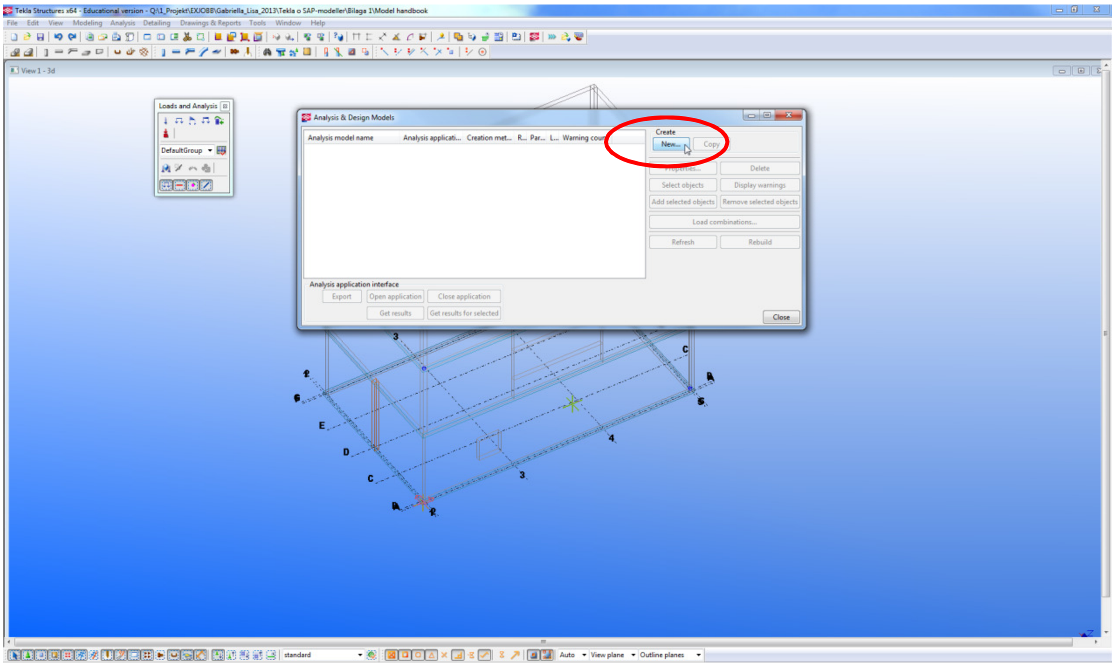
- The list gives explanations to the figures.
- It also gives further instructions which are not included in the figures.

The black textbox gives recommendations and makes the user aware of important occurrences.

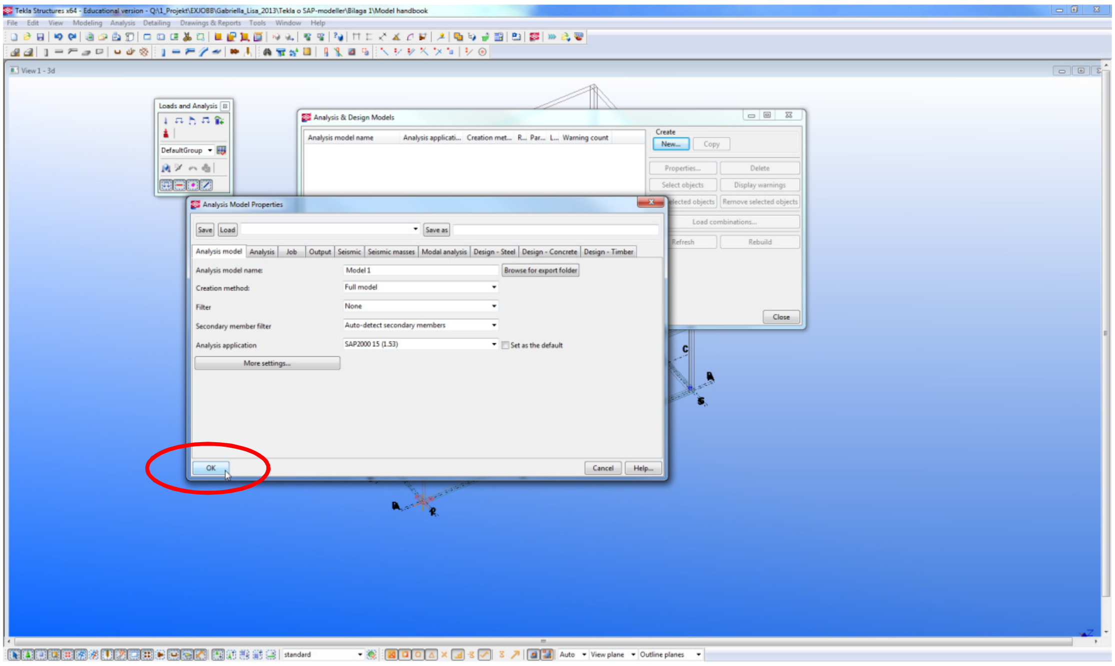
2 Handbook

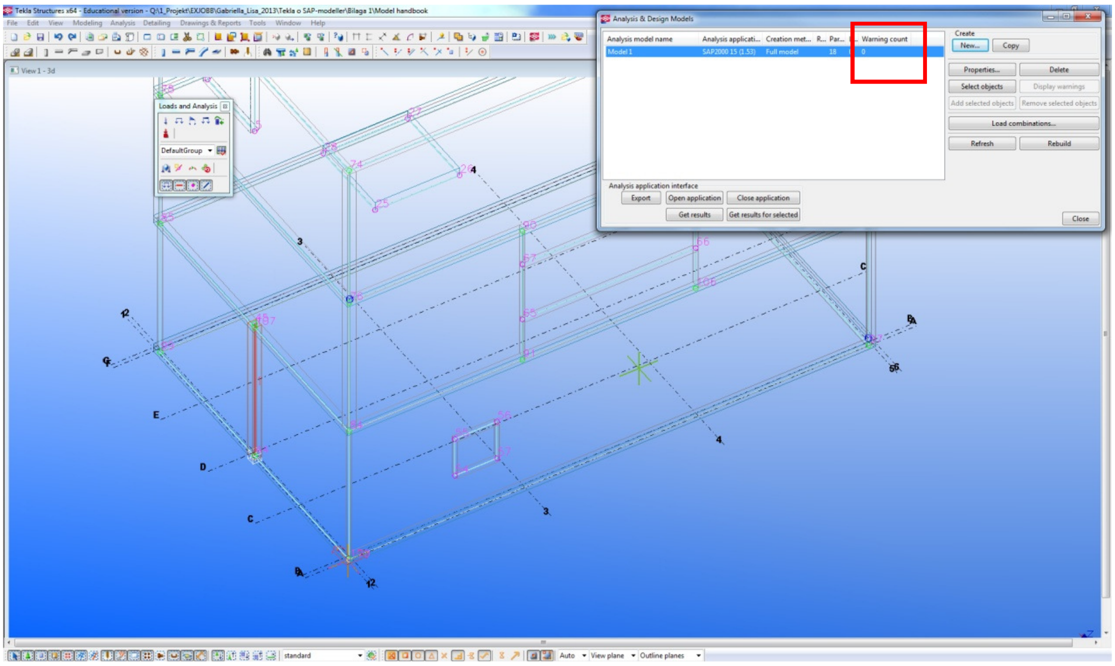
2.1 Creation of an analysis and design model





- Open a model.
- Open Analysis & Design models – Select *Analysis > Analysis & Design models.*
- Create a new Analysis & Design model – Click *New.*

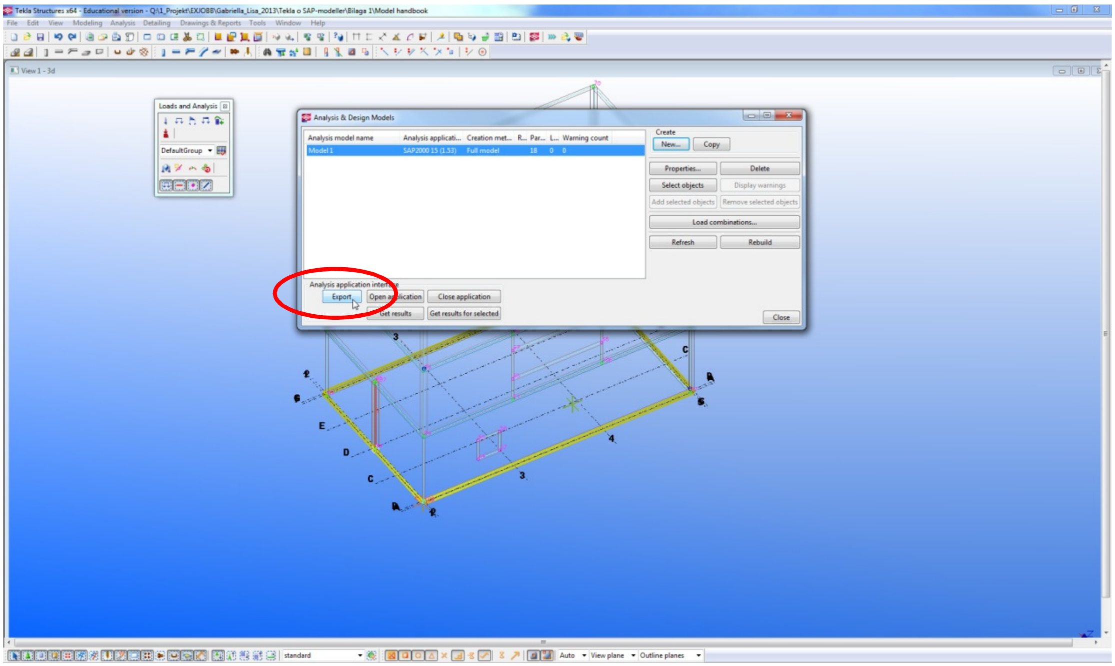


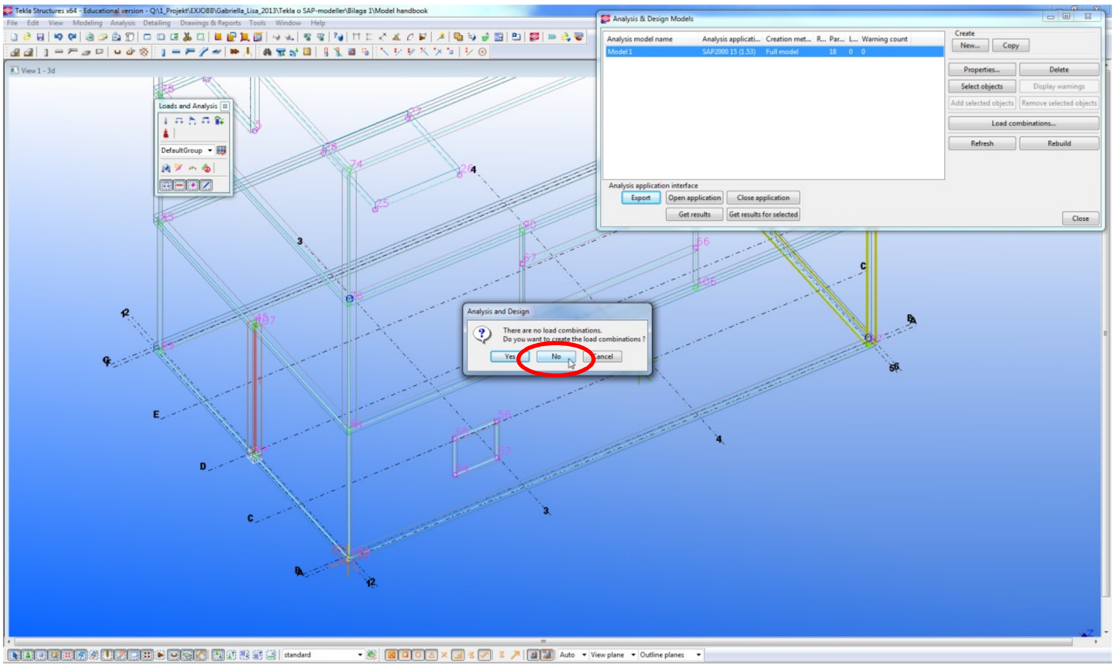


- Accept the settings to create the analysis and design model.
- Check the creation of the analysis lines and nodes by checking the *Warning count*.

The analysis line in the A*nalysis & design model* in TS is translated to a symmetry line in SAP through the export. It is therefore of importance to <u>always</u> study and check the created *Analysis & design model*. Elements aimed to be connected in SAP must share an analysis line in TS in order to be exported as connected elements. Note that, the dimensions of the model in SAP depend on the creation of the analysis lines. It is important to check possible warnings, in the column of *Warning count,* that might arises during the creation of the model.

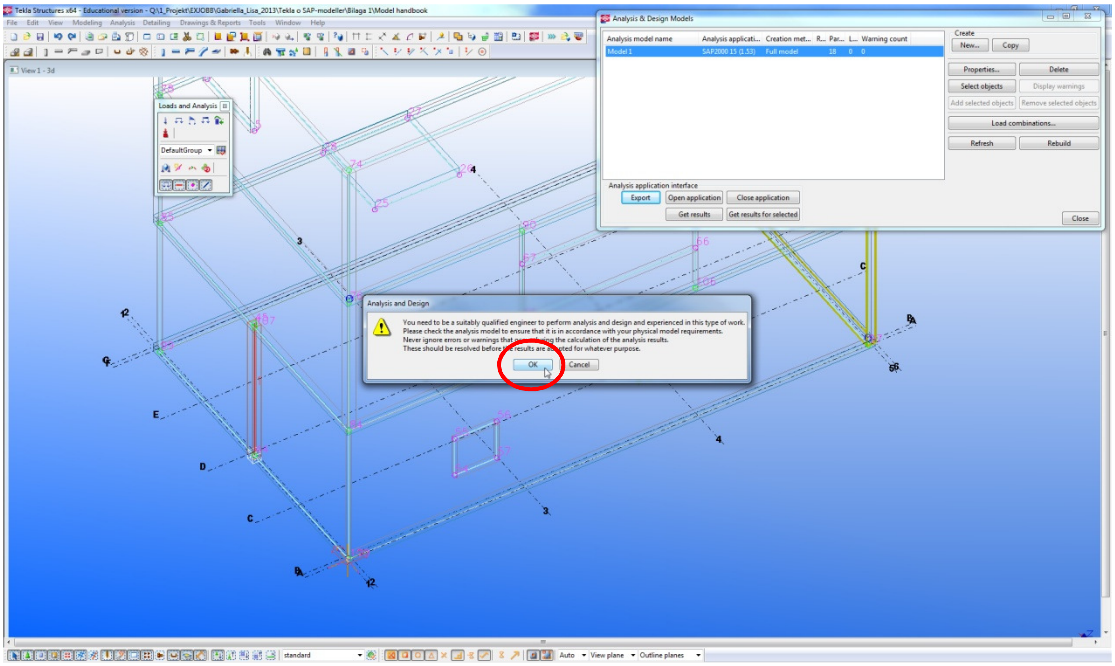
2.2 Export of model

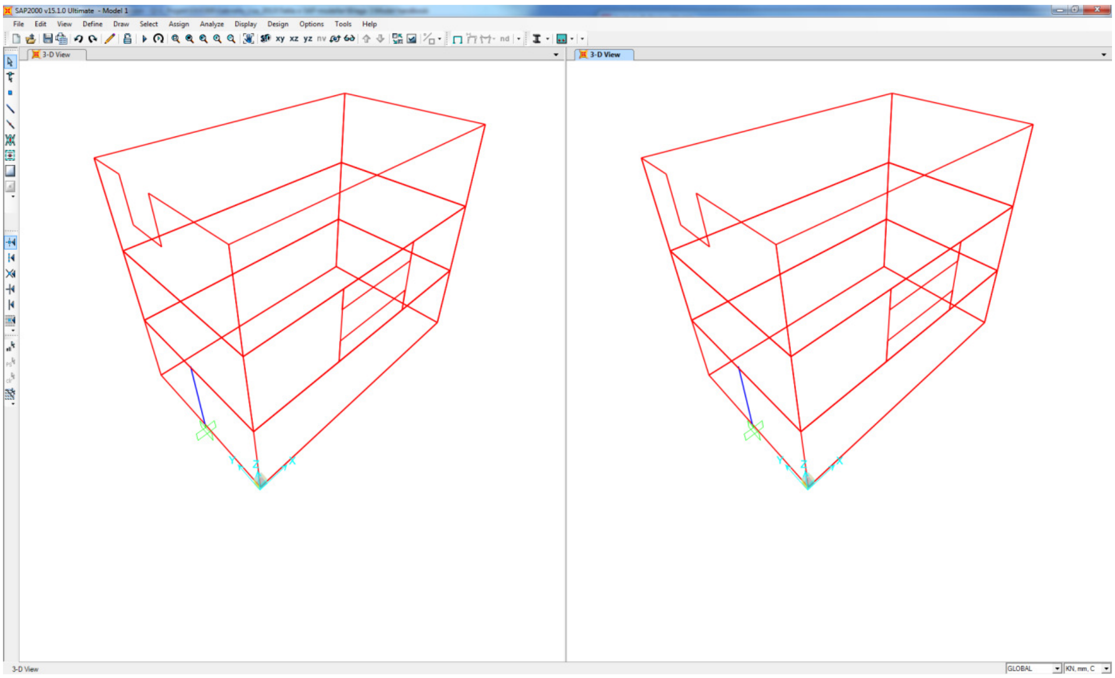




- Make sure that SAP2000 is closed.
- Export the model – Press *Export.*
- Do not create any loads in TS – Press *No.*

Loads and boundary conditions are recommended to be applied by the structural engineer in SAP. SAP must be closed in order for the export to work, otherwise a message appears informing that SAP is opened and the model is not exported. Note that the modelled column is assigned a restraint at the bottom node as default in TS. This restraint is kept for this export.

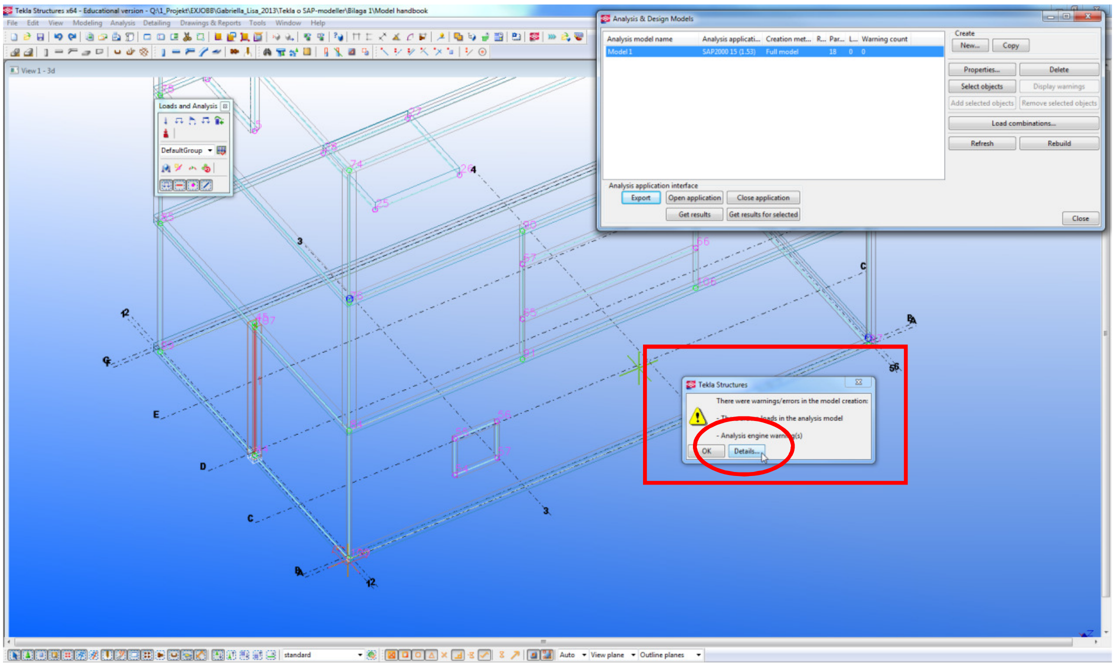


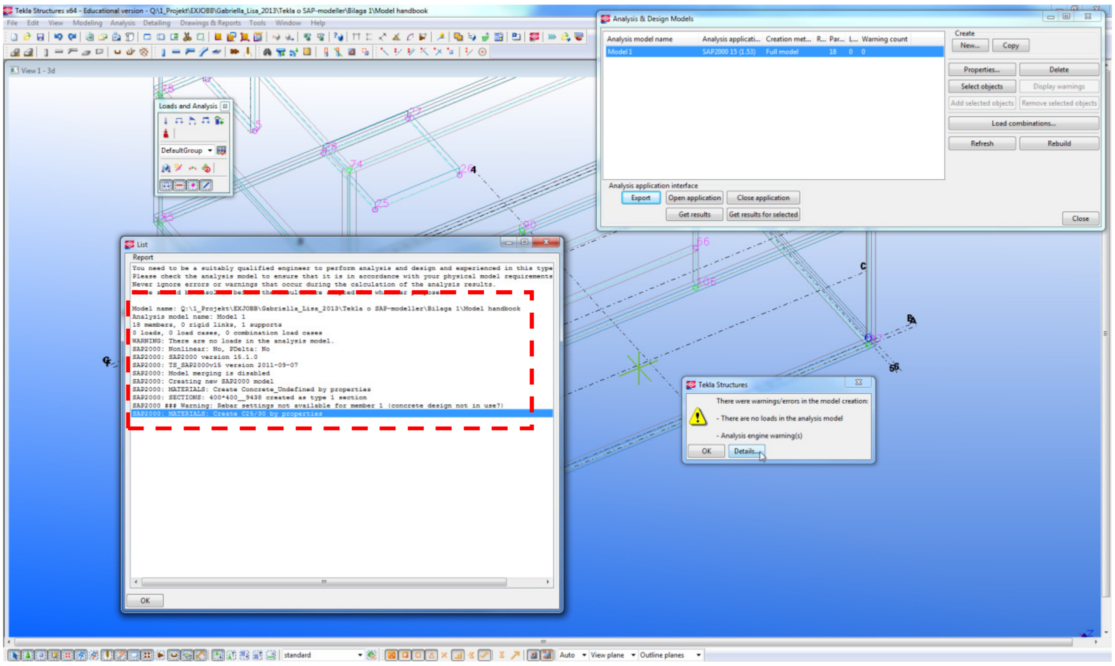


- The user must be a qualified engineer to proceed – press *OK*.

SAP is automatically opened when the Export-link is used.

2.3 Check of warning messages in Tekla Structures

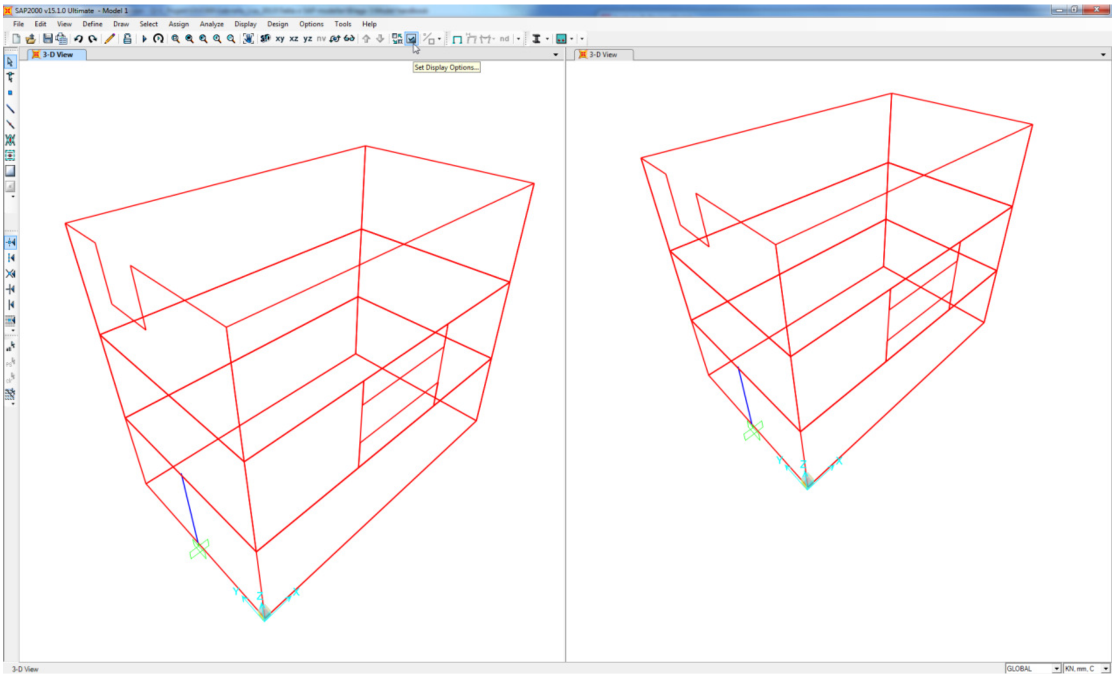


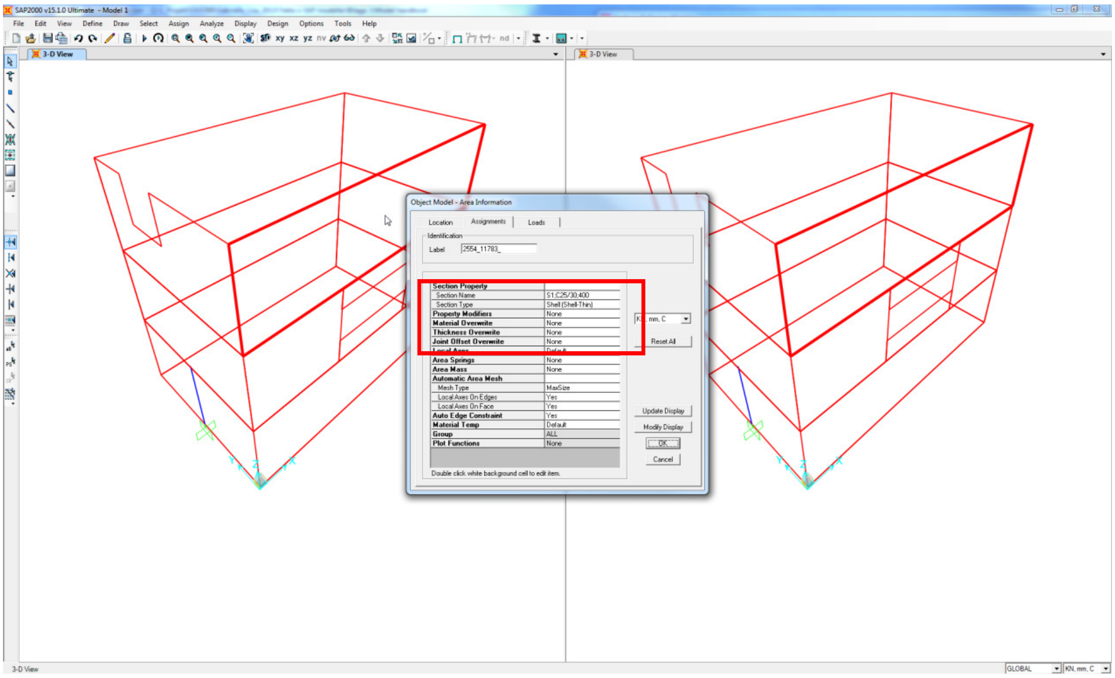


- Minimize the SAP2000 window.
- Check the *warning/errors*
- Read the detailed information about the warning/errors – click *Details*

Since SAP is automatically opened it is important to remember to always check the warnings created during the export, displayed in TS. This could easily be missed as SAP is opened in front of TS.

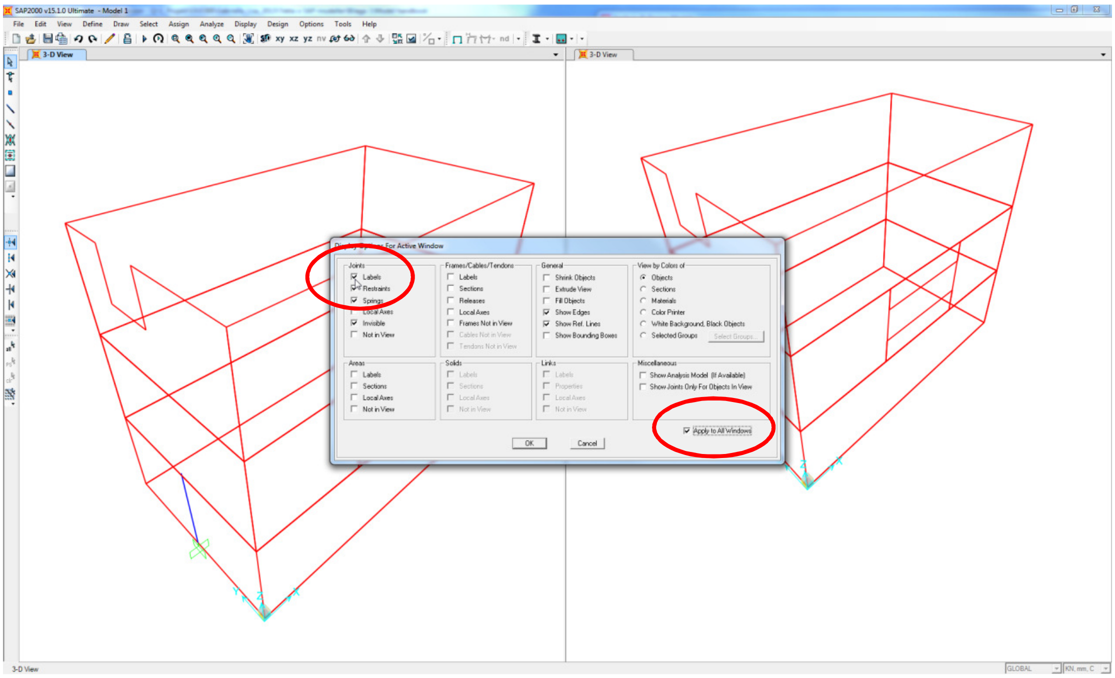
2.4 Check of exported model in SAP

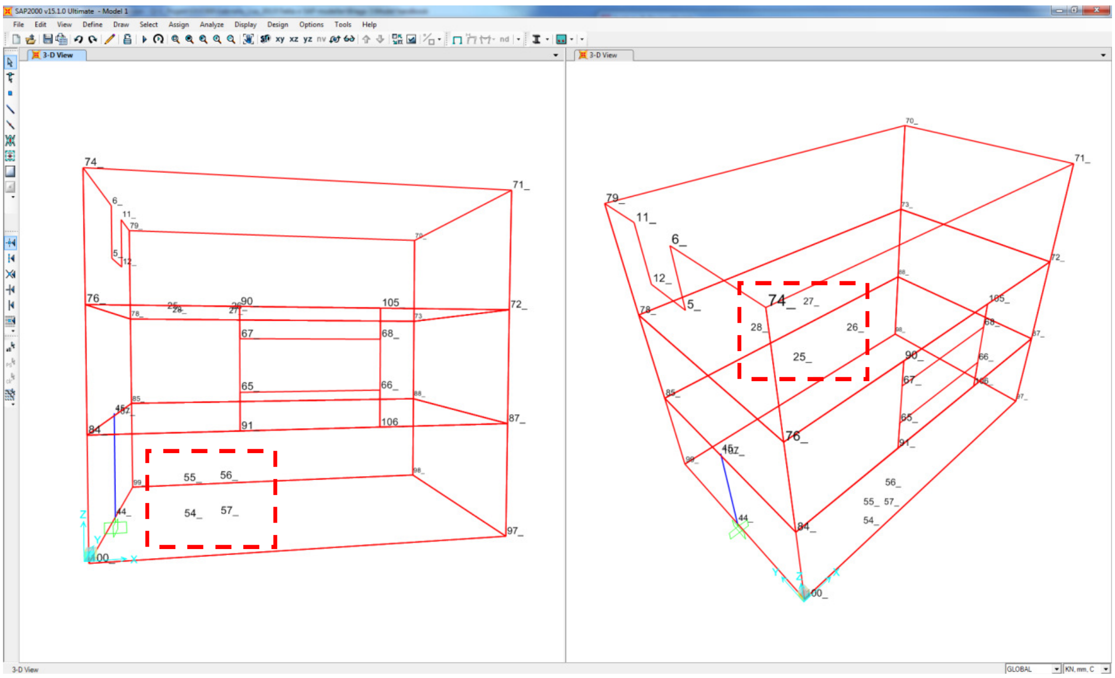




- Check the symmetry lines and nodes in the exported model.
- Check the properties of the elements – Select an area and right click.

Note that the opening at the edge and the opening formed with smaller panel elements are exported while the opening within the panel and the slab are not exported. The restraint assigned to the bottom node of the column in TS is exported. Further on, the material and thickness of the elements are exported.

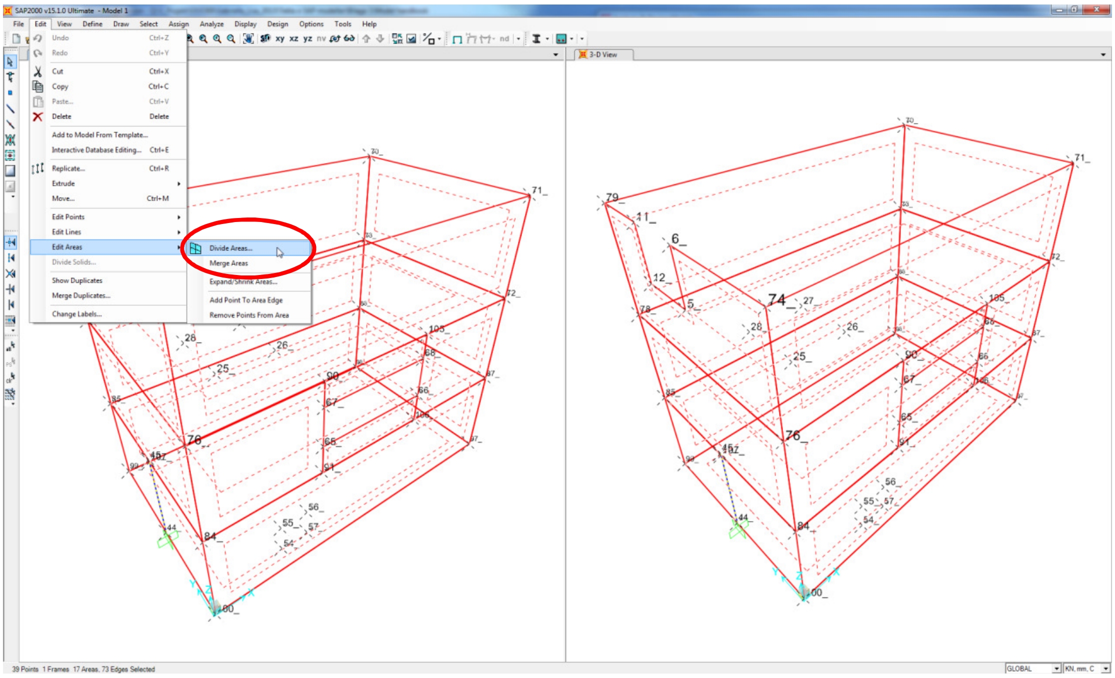


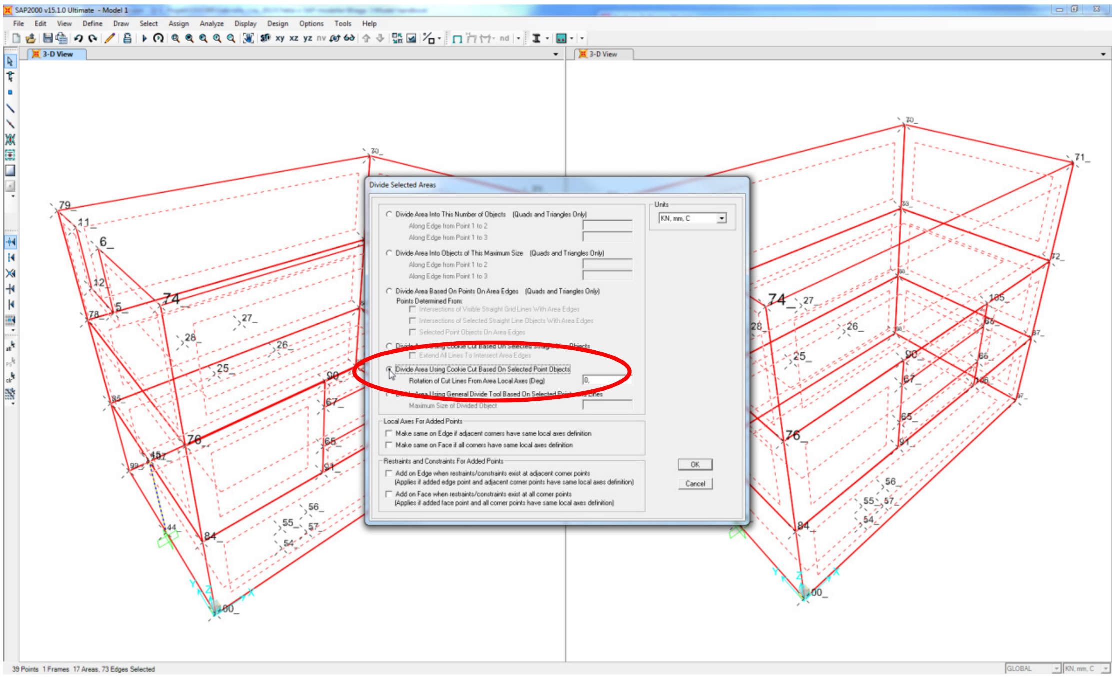


- Open the display options – Go to *View > Set Display options> Display* Options For Active Window.
- Display internal joints graphically in all windows – select *Labels* and *Show to all windows.*

The nodes of the openings are exported and the numbering in SAP matches the numbers defining the opening in TS. By showing these numbers in the model it is possible to find the openings which are not exported.

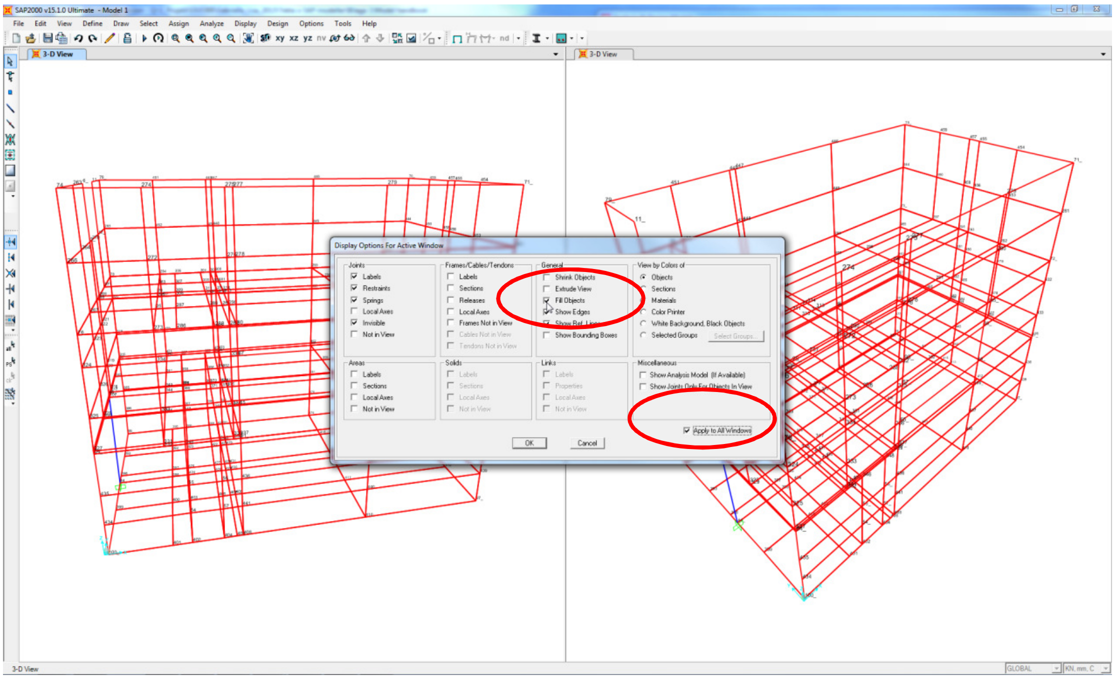
2.5 Creation of non exported openings in SAP

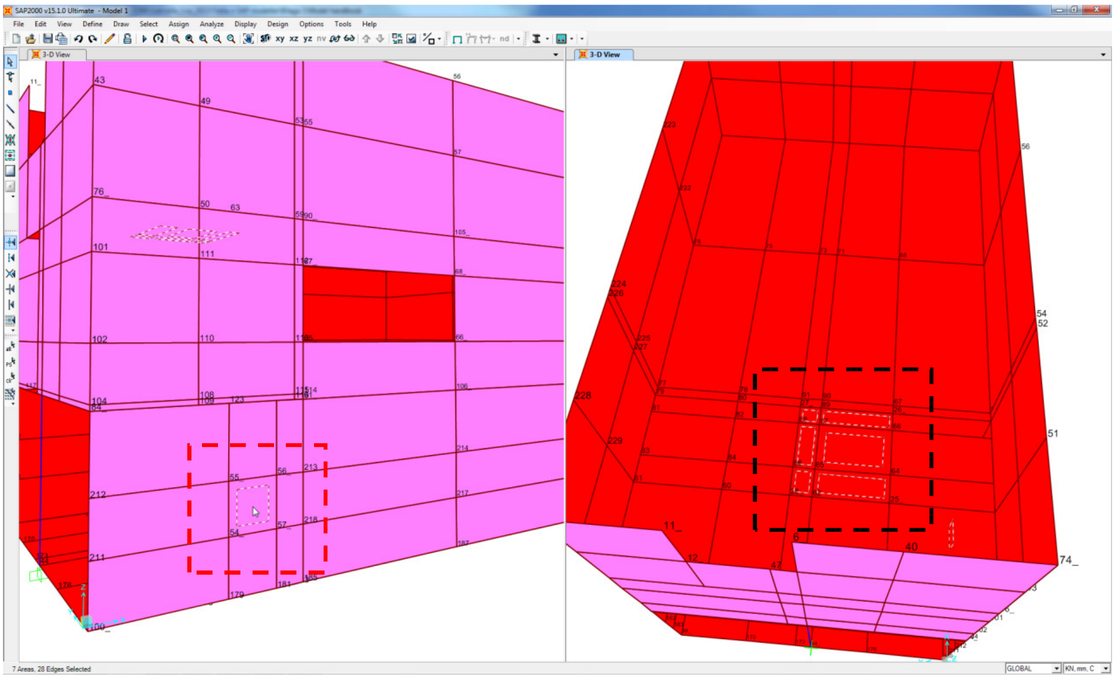




- Select the entire model.
- Open the Divide selected area box– Select *Edit > Edit Areas > Divide Areas.*
- Divide the area based on selected points – *Select Divide area using cookie cut based on selected points objects*.

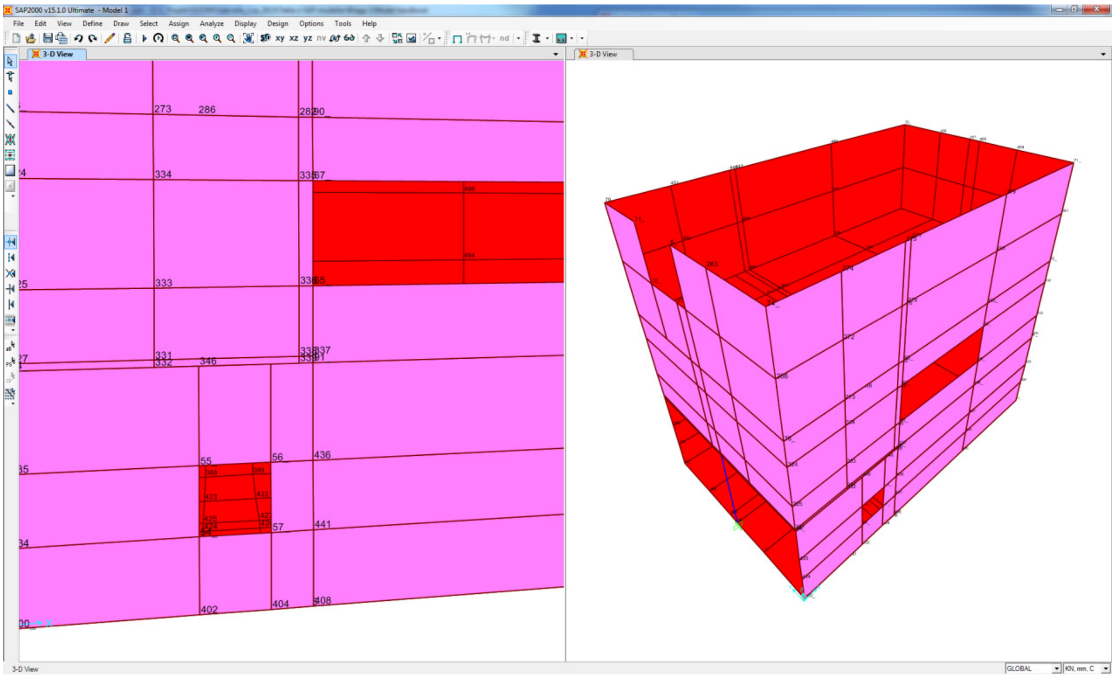
In order to create the openings in SAP, which are not exported, the model must be divided into smaller areas. The division must be based on <u>all</u> nodes in the model.

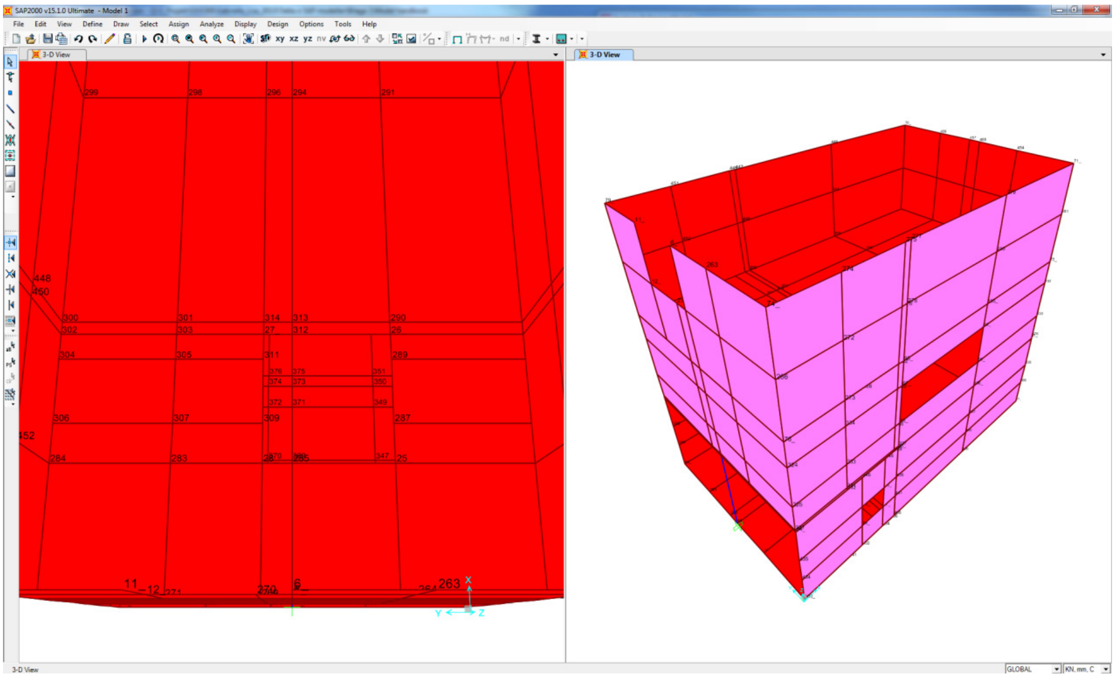




- Open the *display options for active window* box – select *Display > Set display option.*
- Show filled objects in all windows – select *Fill objects* and *Show to all windows.*
- Find the nodes forming the openings and select the area by left clicking.

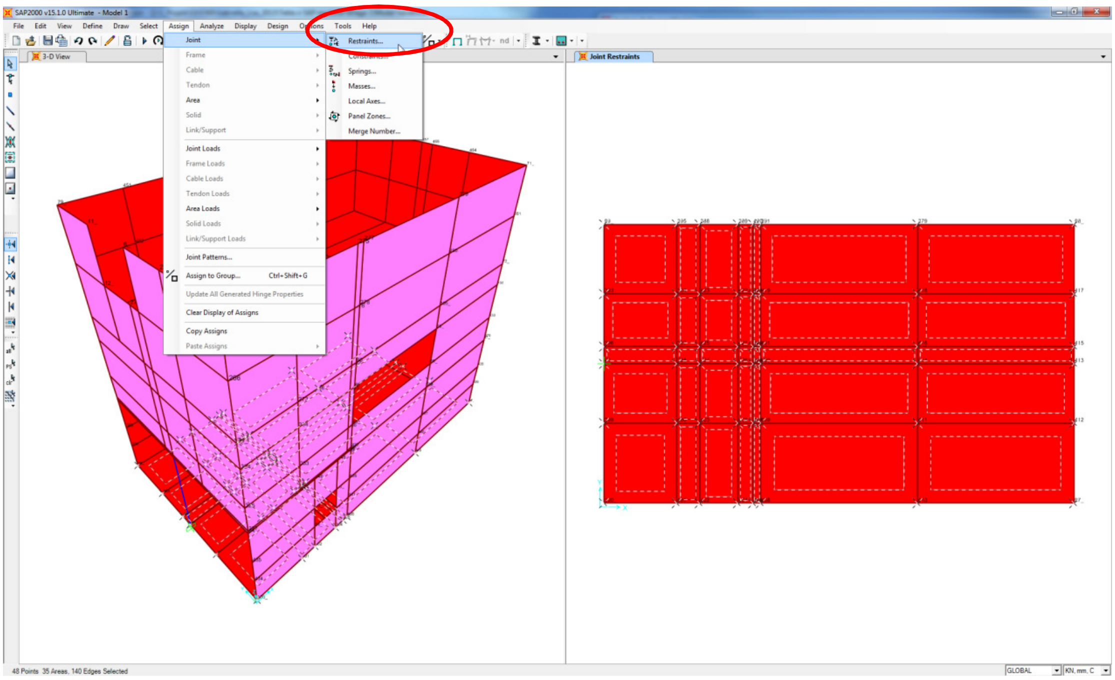
The user must find the smaller areas defining the opening with the assistance of the numbered nodes.

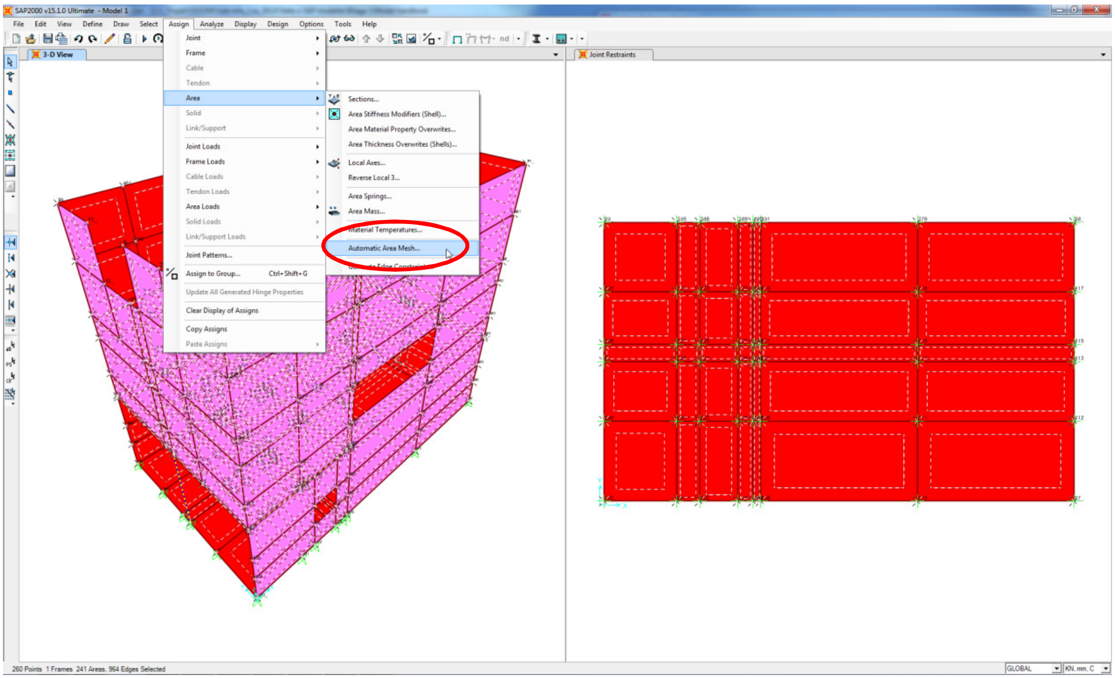




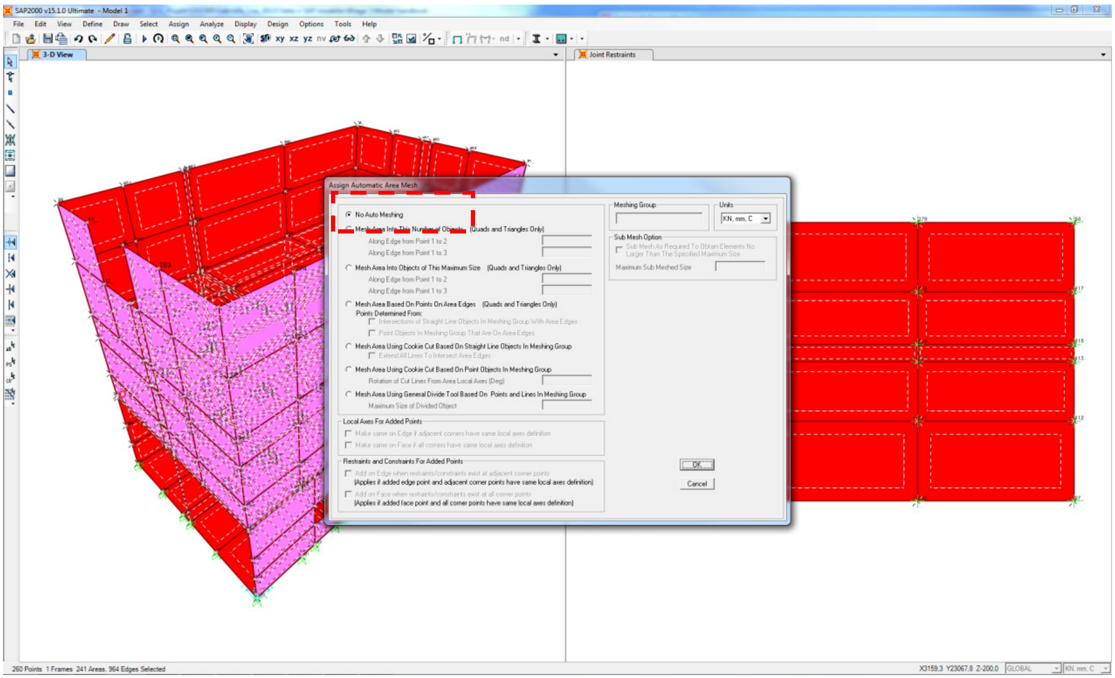
- Press the *delete* key in order to erase selected parts and to create the opening.

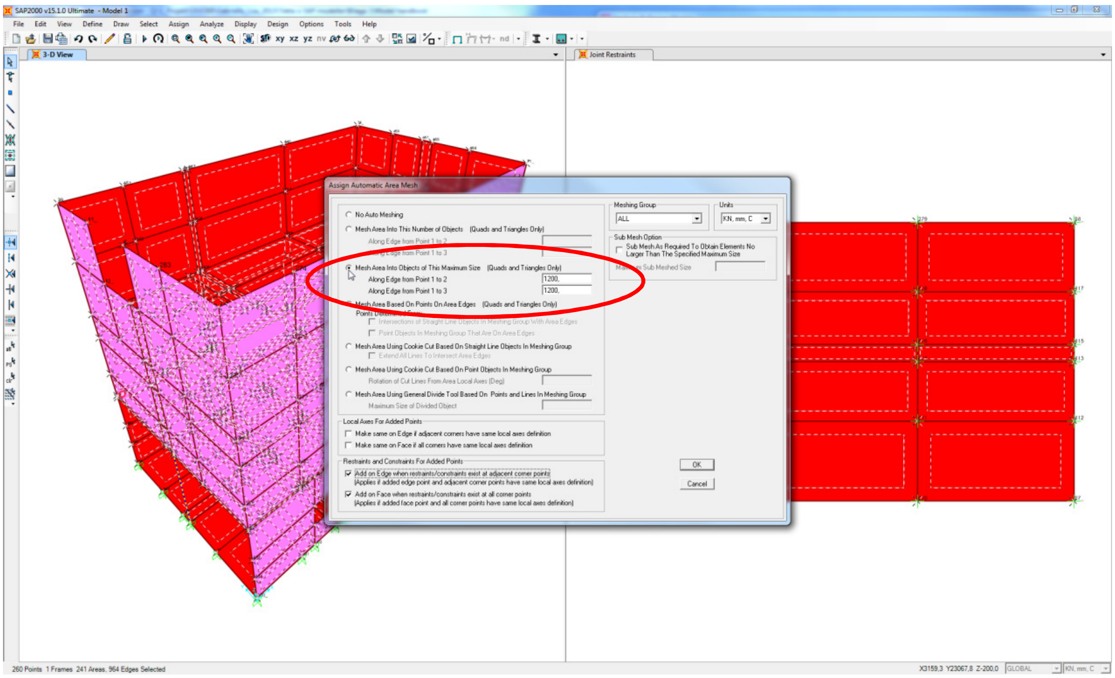
2.6 Definition of boundary conditions and choice of mesh





- Select all nodes on the bottom slab in order to define boundary conditions.
- Define restraints to the selected nodes – Use the command *Assign > Joint > Restraints.* Chose the requested typ of restraint.
- Select the entire model
- Open the Assign automatic area mesh box – Go to *Assign > Area > Automatic area mesh.*

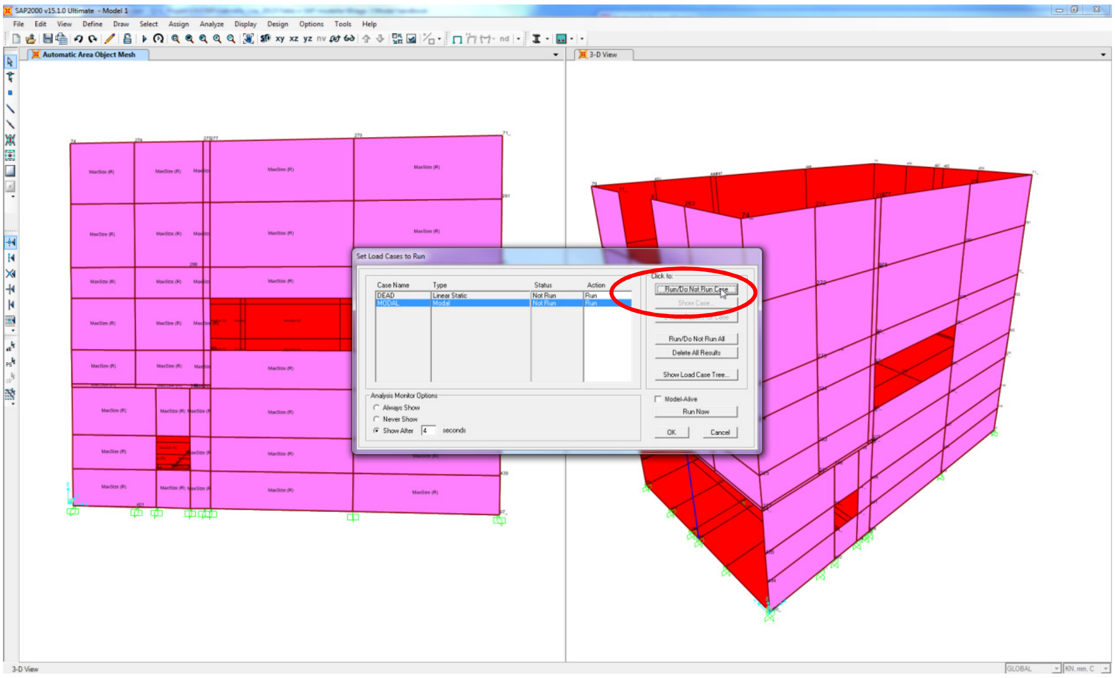


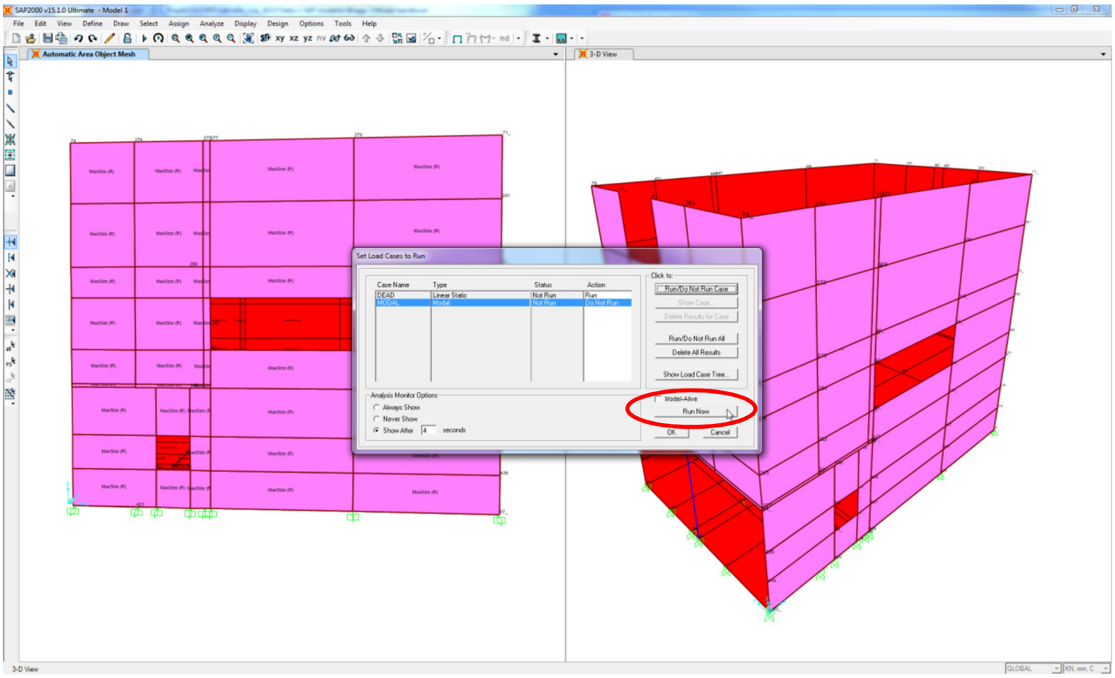


- Mesh the structure into objects with a specified maximum size – Select *Mesh area into object of this maximum size (Quads and Triangles Only)* and define a maximum size.

Note that the program always recommends no automatic mesh after using the command *dividing areas*. In order to mesh the model, another meshing option must be selected.

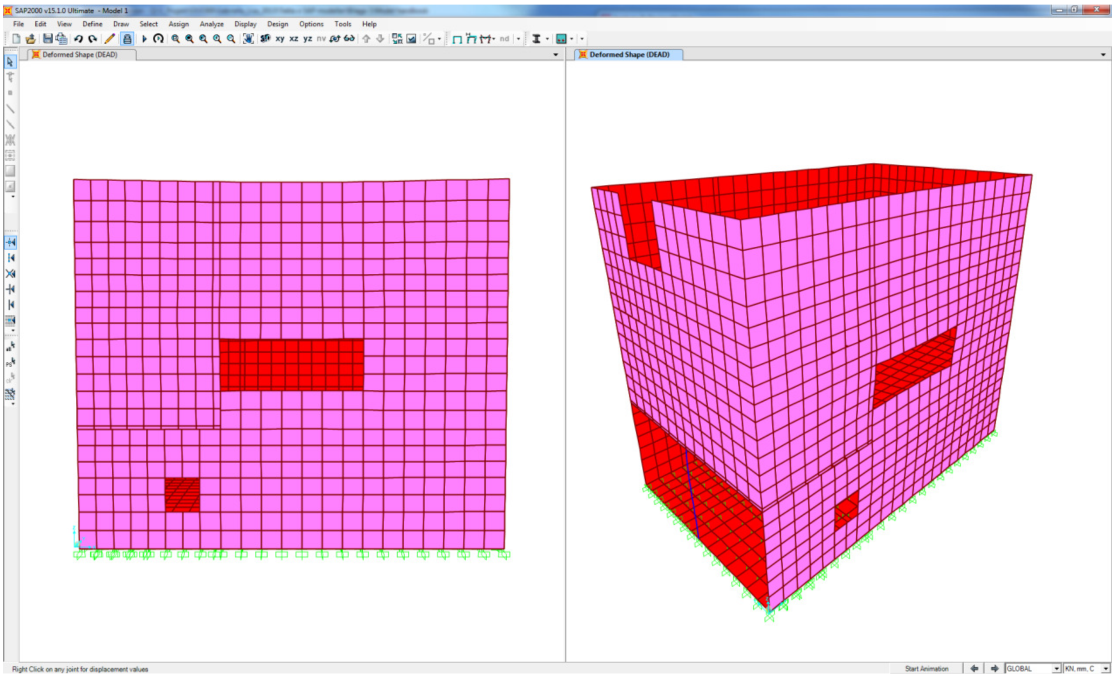
2.7 Analysis





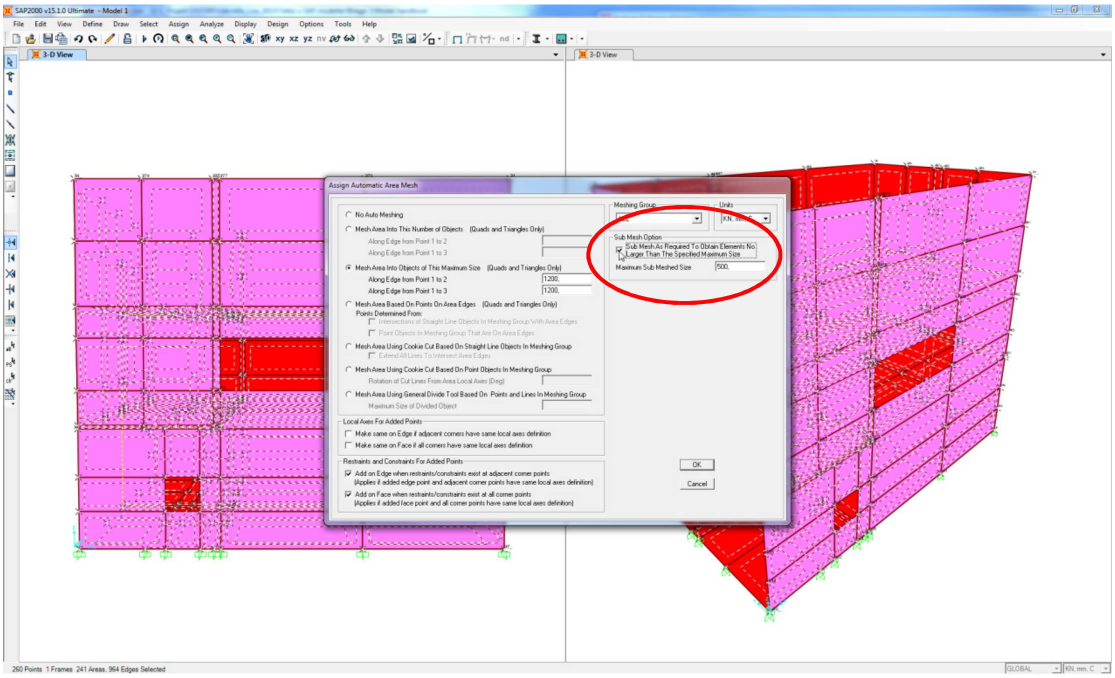
- Open the *Set Load Cases To Run* box – Go the *Analyse* > *Run Analysis*
- Run only the linear static analysis – Select the line for the modal case and click *Run/Do not run case.*
- Run the analysis – Click *Run now.*

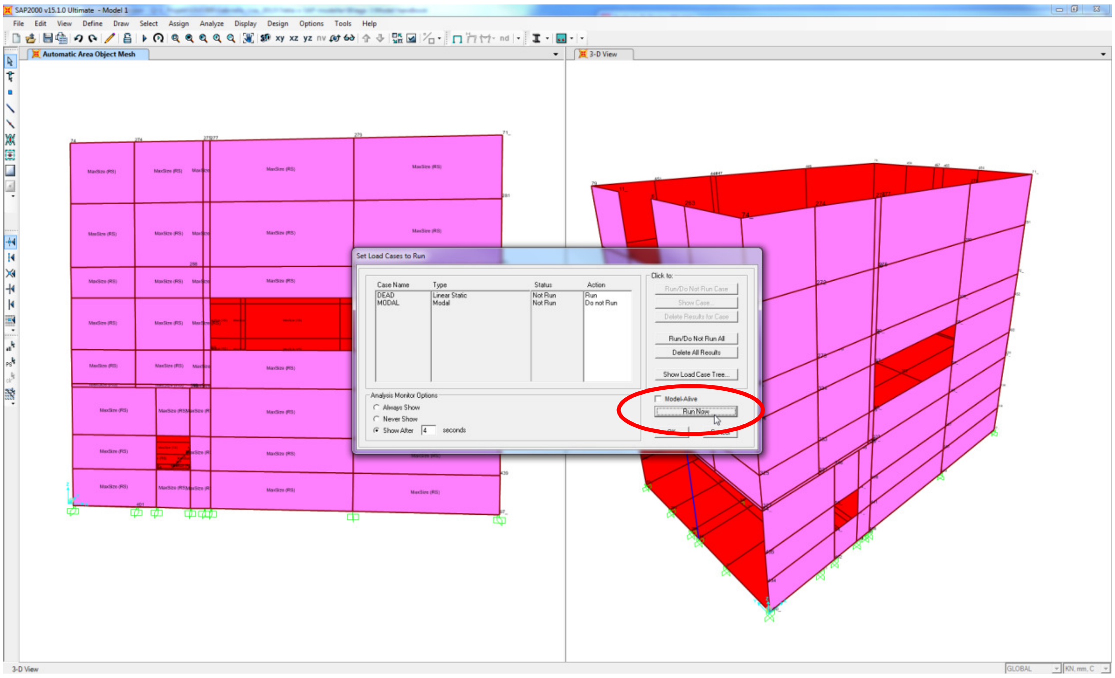
A static analysis is performed in order to see if the model is behaving as suspected.



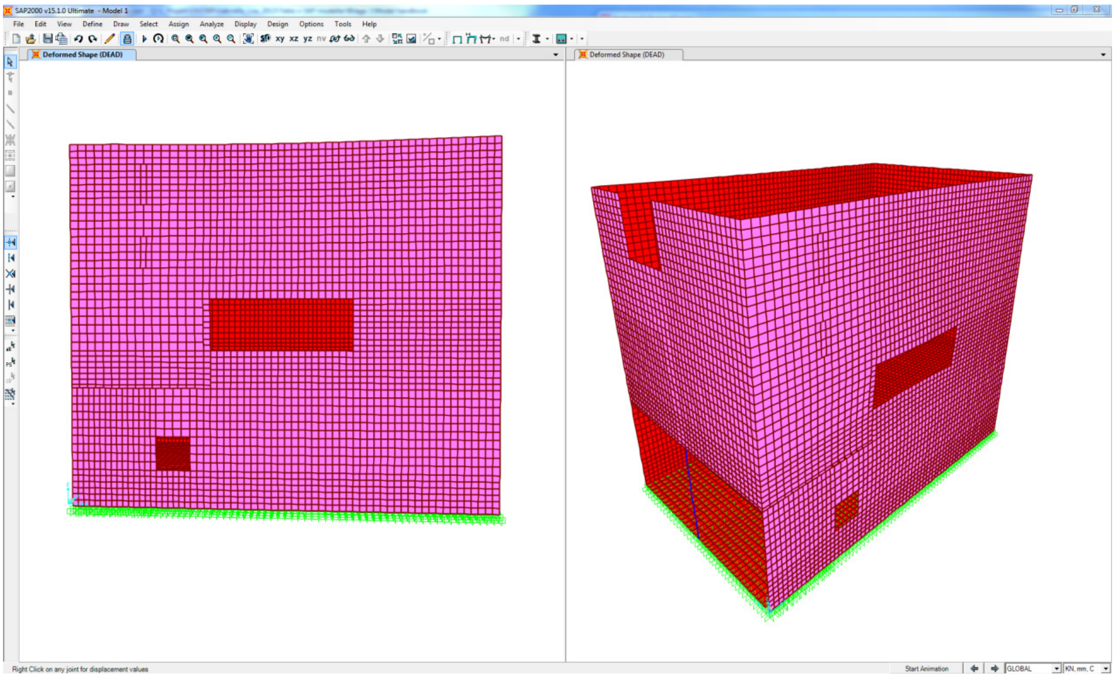
The model is analysed influenced only by dead weight and the result is displayed by a deformed shape. In order to get a more fine mesh the following steps can be included in the work (see next page).

2.8 Refining the mesh





- Choose the same meshing option as before.
- Select the *Sub mesh as required to obtain elements no larger than the specified maximum size* and define a *maximum sub meshed size*.



The model is analysed influenced only by dead weight and the result is displayed by a deformed shape. The new mesh which is generated is finer.

3 Other observations

There are a number of observations that occurred during the case study in the Master's project which are not presented in the step by step-instruction. These are collected in the list below.

- It is not possible to get a regular mesh with rectangular elements for a panel or slab which contains circular opening. Instead, as far as possible, it is suggested to model rectangular openings instead of circular openings. It is recommended for the structural engineer to erase possible circular openings to ensure a correct mesh.
- Parts which are only "partly cut out" are not exported. "Partly cut out" can be described as a part which is not totally cut through but only partly cut into the element.
- For panels and slabs without modelled openings it is possible to use the auto mesh chosen by the program.
- The modelling techniques used for creating of openings in the model are an example of techniques available in TS. It has been shown that the export of openings is independent of modelling technique.

Preface

Appendix 1: *Detailed presentation of implementation of the case study - Compatilibity of Tekla Structures and SAP2000* is a appendix to the Master's project *Integrated work of the CAD-technician and the structural engineer.*

The master's project aims to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in the design phase. The Master's project focuses on the two important aspects communication and linking knowledge. The compatibility of Tekla Structures and SAP2000 is studied through a case study and by investigating the export of panel- and slab elements from Tekla Structures to SAP2000, feasibilities and limitations of the compatibility are obtained. Further on, a discussion of the feasibilities and limitations are resulting in recommendations for the export.

The purpose of the case study was to examine the compatible link between Tekla Structures and SAP2000 through studies treating the export of panel and slab elements, openings in such elements and panel and slab elements connected to beam and column elements. A well working communication between the programs is of high importance in order to enable better coordination and integrated working method in the design phase. Through the investigation of the compatibility of the software the ability of a more integrated work between the CAD-technician and the Structural engineer was studied. The result of the case study is presented as feasibilities and limitations for the export. Finally, the two aspects and the deeper investigated compatible software are together discussed in order to generate conclusions that facilitate a more integrated work of the CAD-technician and the structural engineer in the design phase.

The appendix aims to report the execution, step by step, of the case study. In the appendix a describing text about the pictures is presented, followed by the informative figures. For detailed conditions and presumptions refers to the Master's report, chapter 3.1. This appendix is recommended to be read in digital form.

Advice and recommendations for the export is presented in Appendix II: *Manual of the export from Tekla Structures to SAP2000*

In the appendix two shortnotations are used:

TS – Tekla Structures
SAP – SAP2000

Gothenburg june 2013
Lisa Beckman
Gabriella Milveden

Contents

1 Export of panel and slab elements

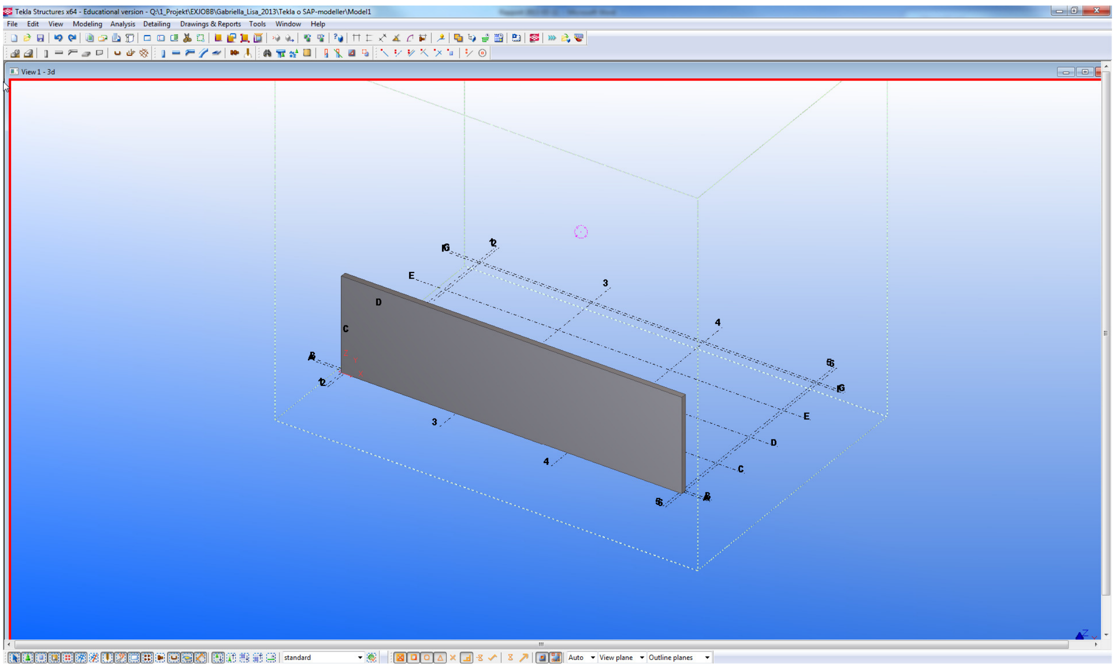
The purpose of this study was to identify feasibilities and limitations of the export of panel and slab elements from TS to SAP.

The case study was divided into three studies:

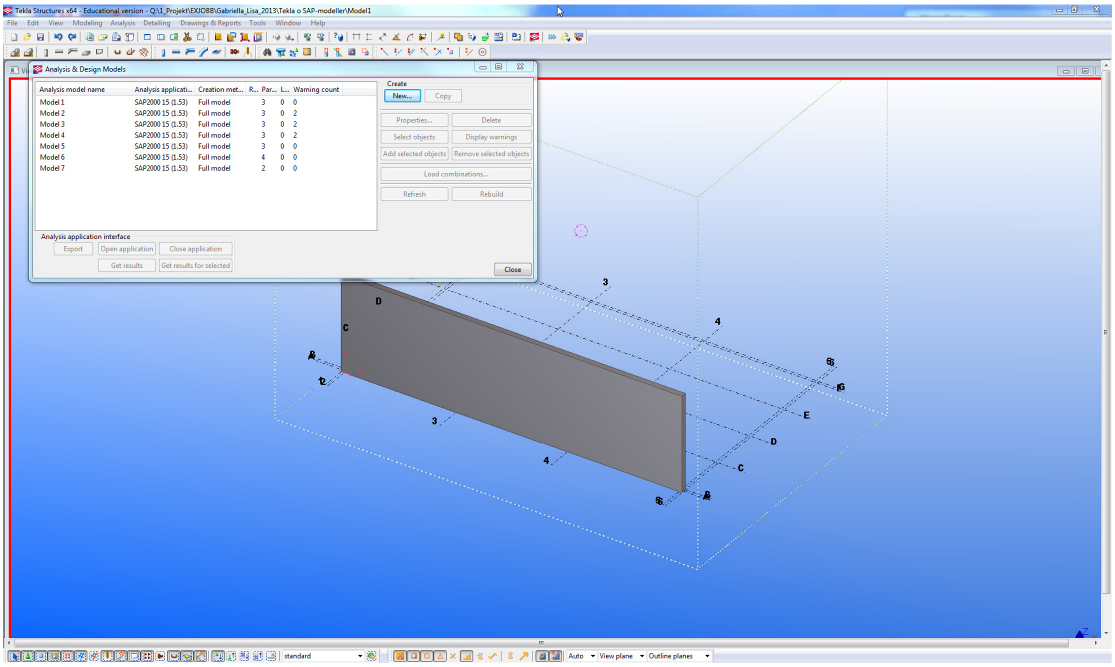
- Export of a panel element.
- Export of a panel element in connection to a slab element.
- Export of connected panel and slab elements.

1.1 Export of a panel element

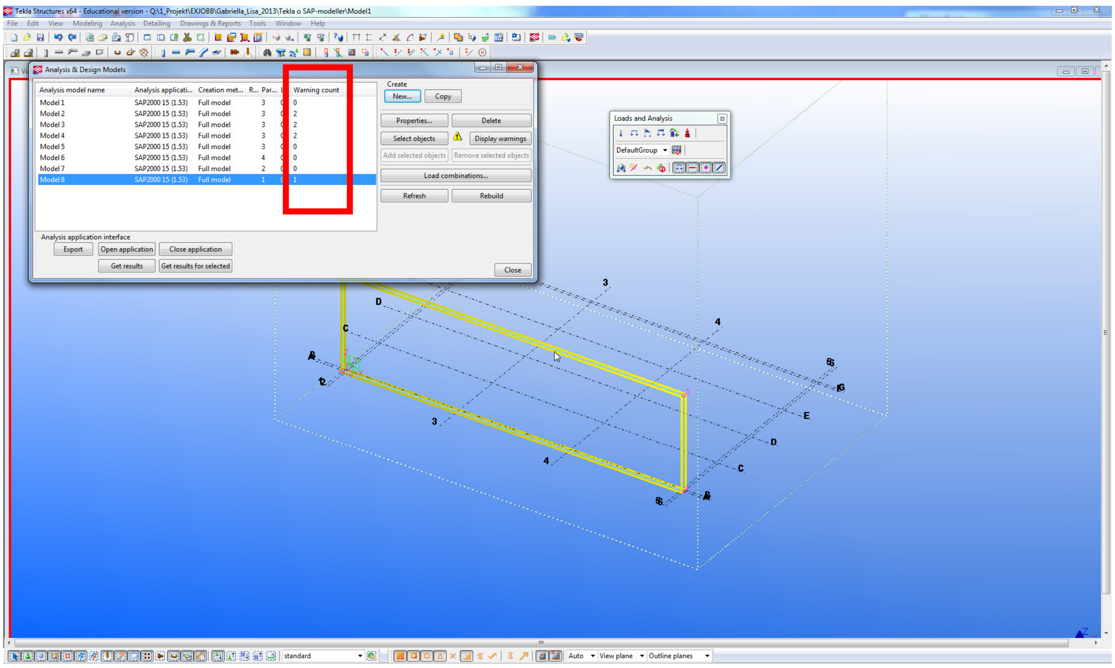
1. An element was modelled by the *Concrete panel*-tool in TS. Material properties and the thickness of the panel were defined, by double-clicking on the panel, to C25/30 and 400mm. The model was created in TS without assigning any loads or supports, which was done for all further studies.



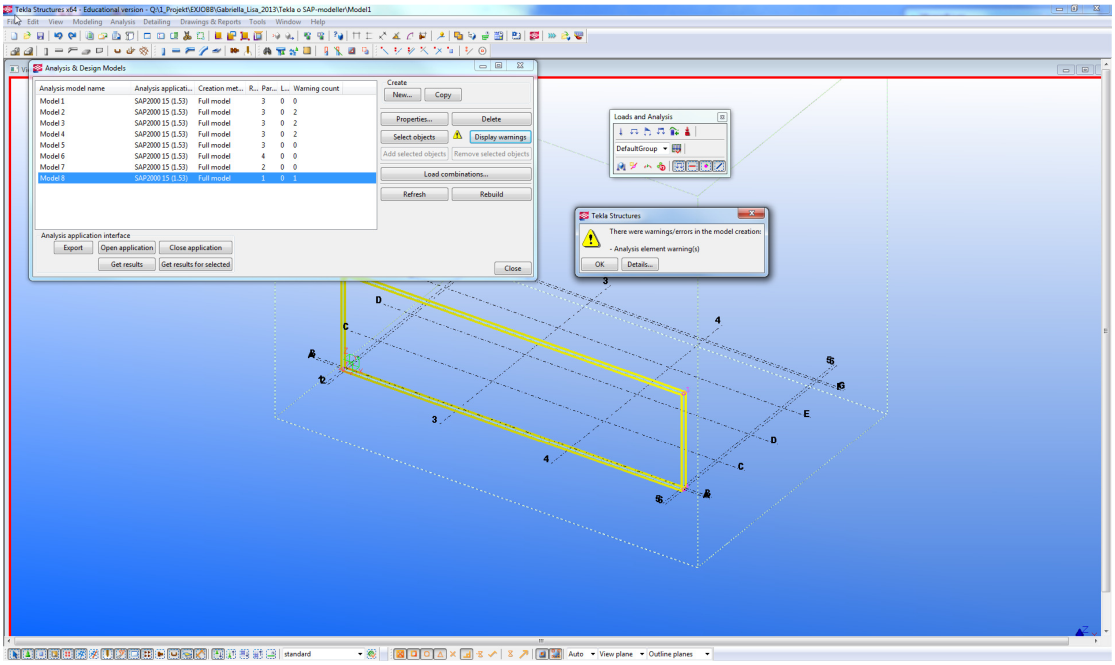
2. The *Analysis & design model* box was opened.



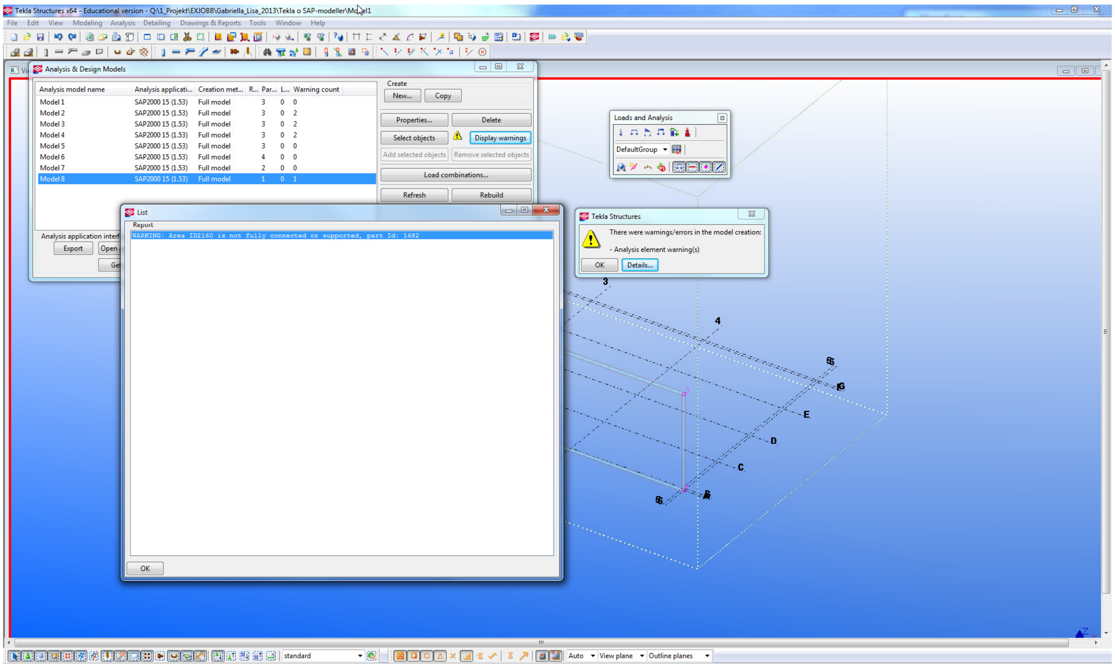
3. An *analysis & design model* was created. Analysis lines were displayed as highlighted yellow lines with nodes at the corners. During the creation of the *analysis & design model, warning counts* can appear. These must always be controlled by the user, and if necessary be fixed.



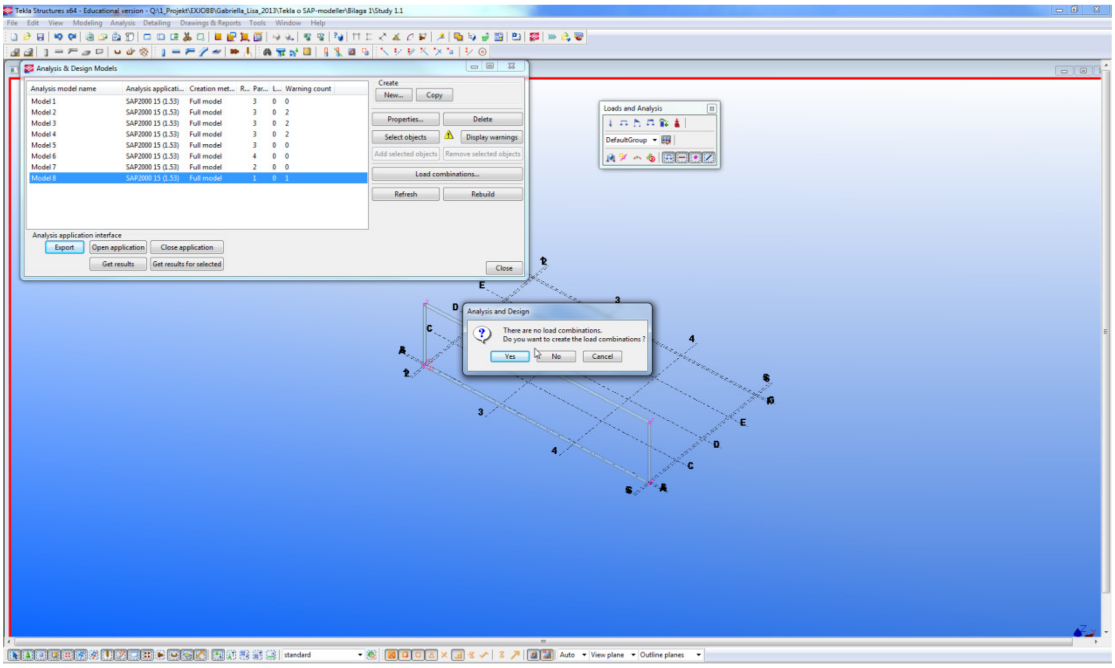
4. To get detailed information about the *warning counts* the function *Display warnings* was used and the *warning counts* for the analysis was defined as *“Analysis element warning(s)”*.



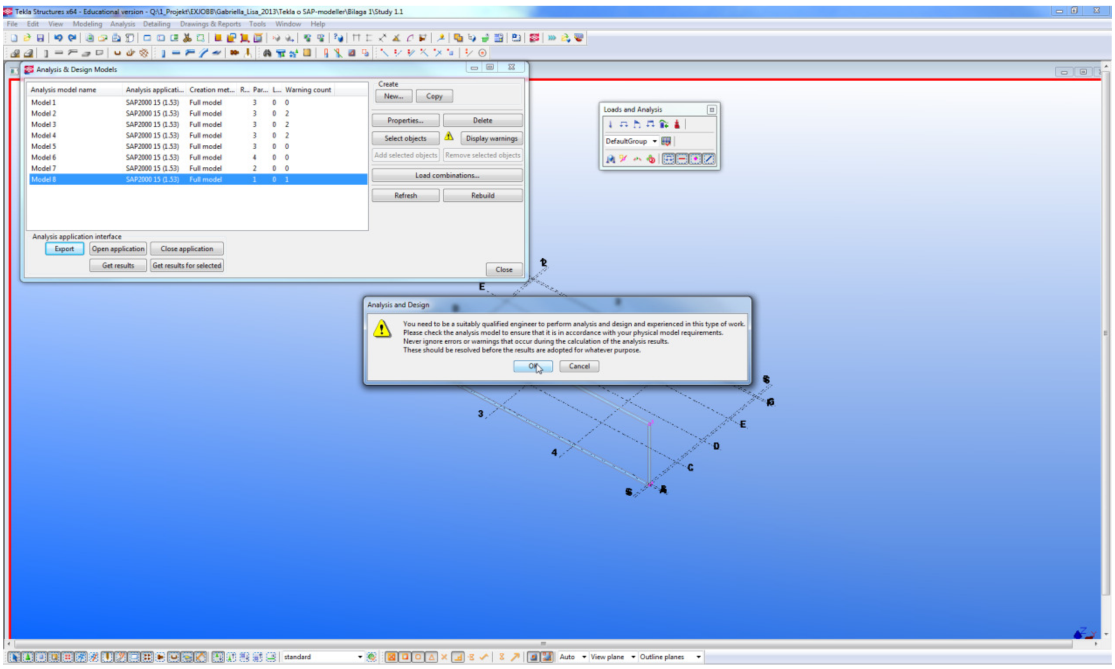
5. Further details about the warnings were displayed by the function *Details.* The report described that the panel was not fully connected or supported. In this case the *warning count* did not need to be fixed.



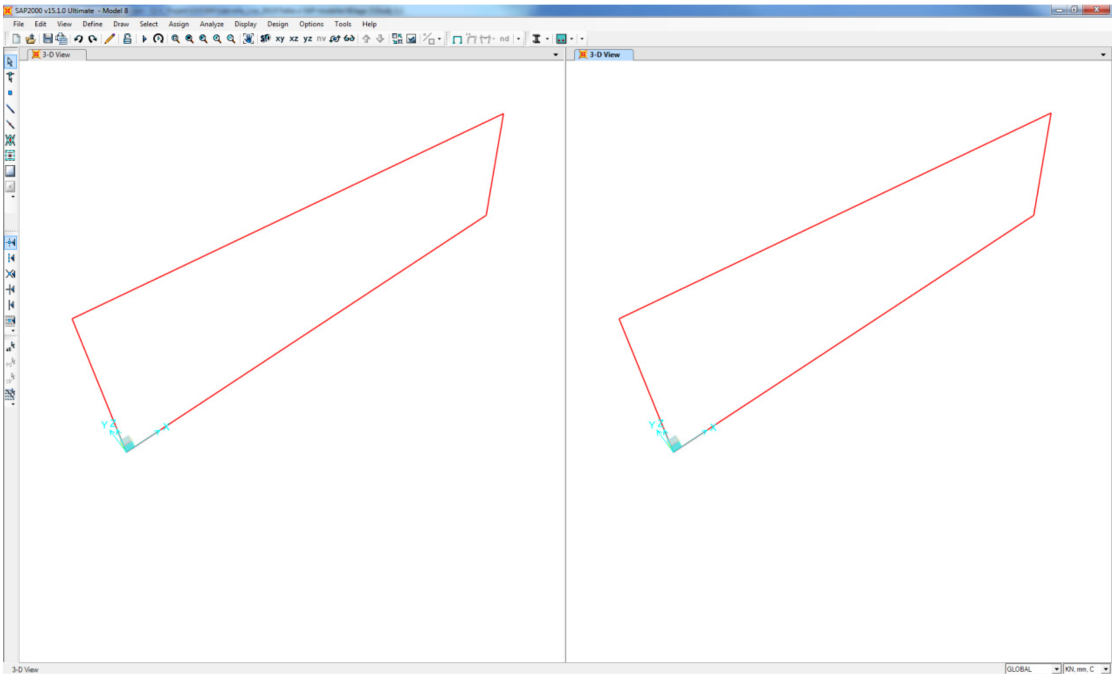
6. The *export* function was now used. A message appeared concerning creation of load combinations in TS. Since the loads should be applied by the structural engineer in SAP the option “No” was chosen. This message is a standard message that appears for <u>every</u> export if no load is applied in TS.



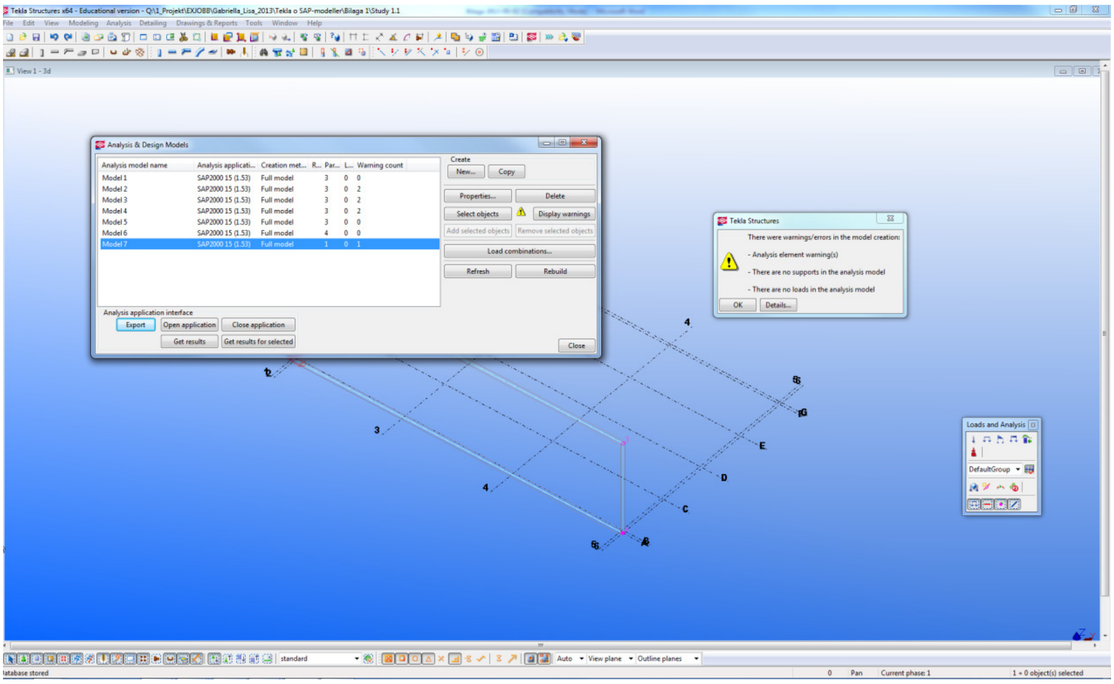
7. Information about the fact that the user need to be a “suitable qualified engineer” to perform the analysis and design was displayed. Also this is a standard message that appears for <u>every</u> export.



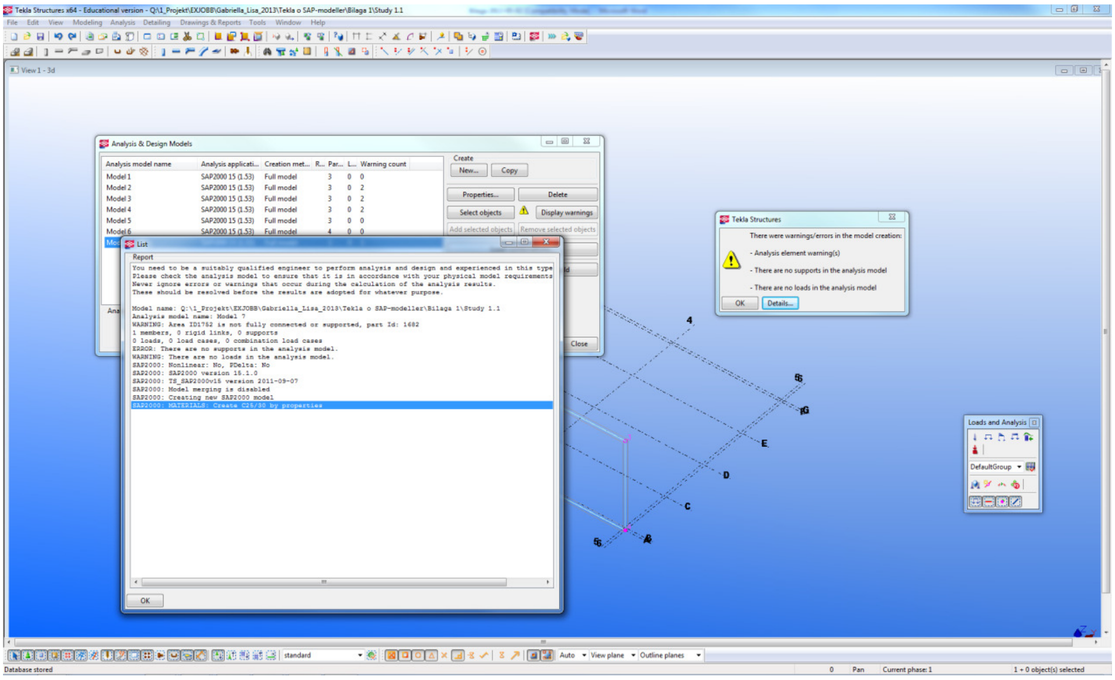
8. The model was exported to SAP by clicking on the *Export*-bottom and SAP was automatically started. Note: SAP opens with the units kN, mm and C.



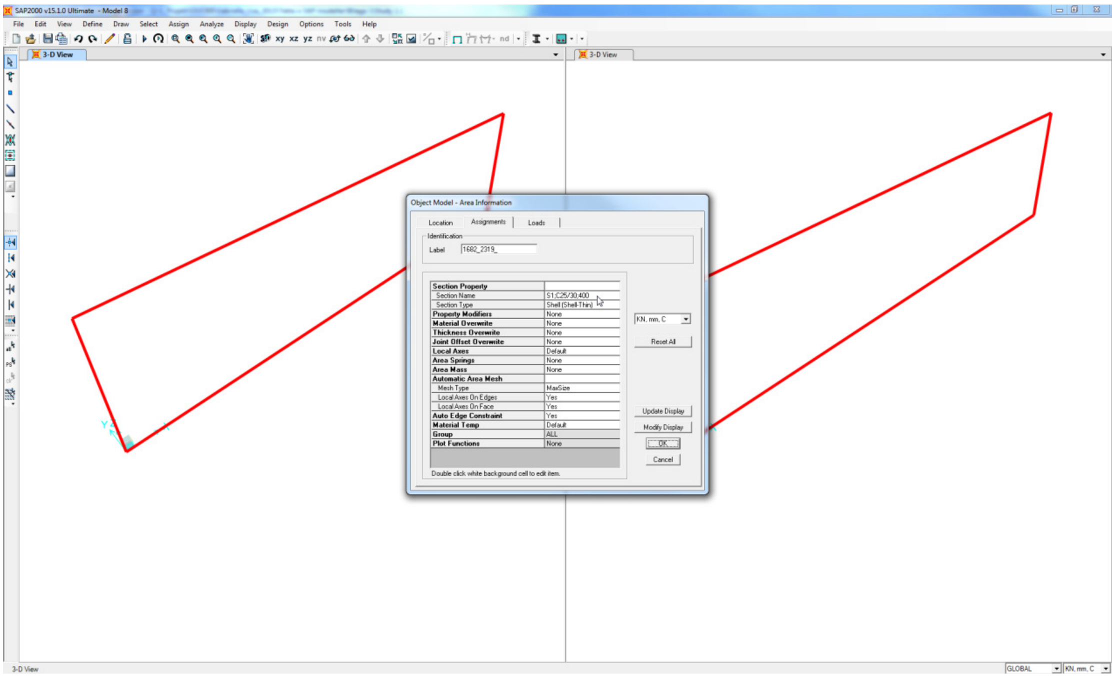
9. The *warning/error messages* that appear in TS at the export were checked by minimizing the SAP window. It is of importance to always check these messages.



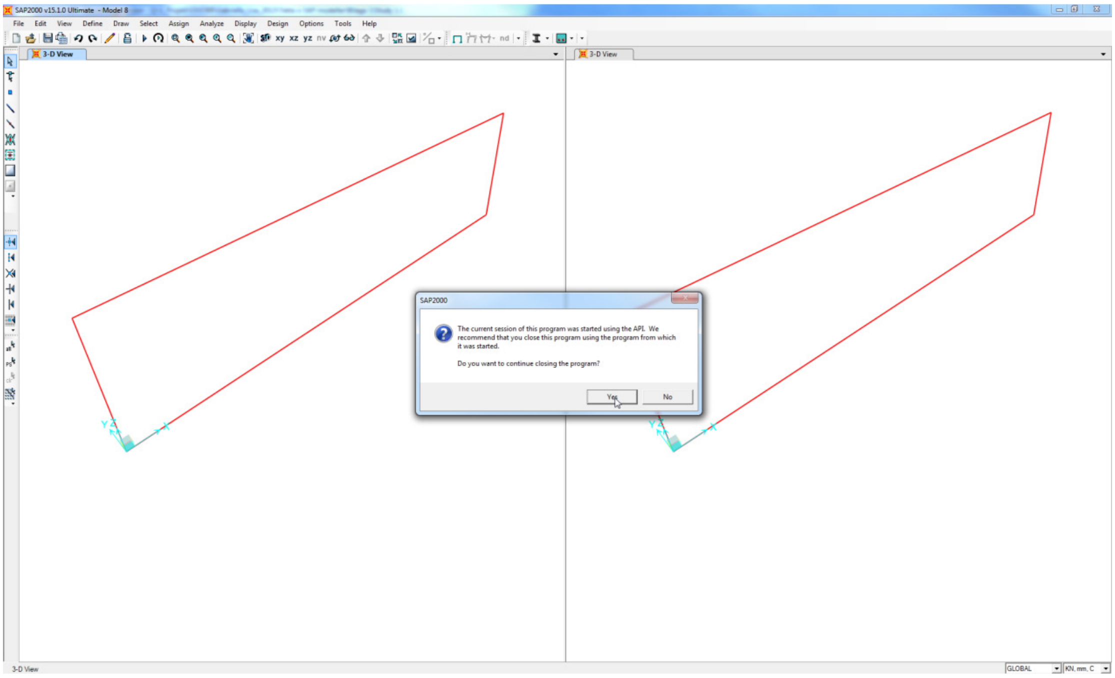
10. Further details about the warnings were displayed by the function *Details*. The report described that the element was not fully connected or supported and that there were no loads applied. In this case the *warning/error messages* did not need to be fixed



11. The exported model was examined with the *Object Model – Area Information* box, which was displayed by right clicking in the model. The *Section name* was controlled which gave information about the material, the thickness of the concrete and that the *Section type* was a shell element. All assigned properties from TS were exported to SAP.

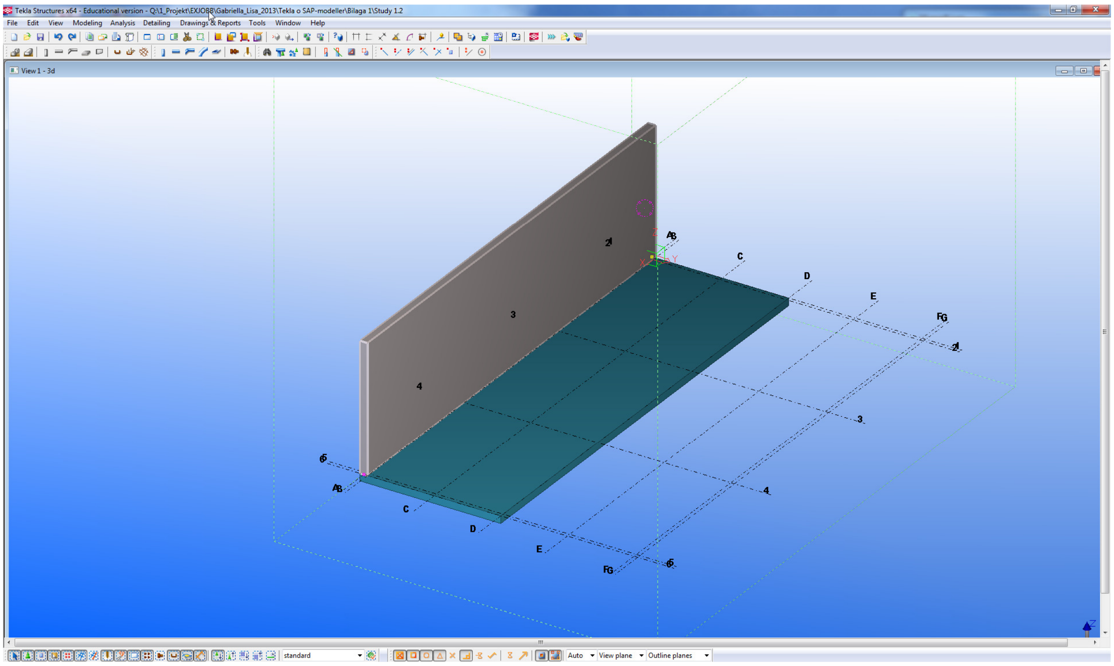


12. SAP was closed by the X-button and a message appeared concerning the *Export*-link. The message recommends that SAP should be closed from the program of which it was started, i.e. TS. This message was ignored because no further investigation was planed and the program was closed.

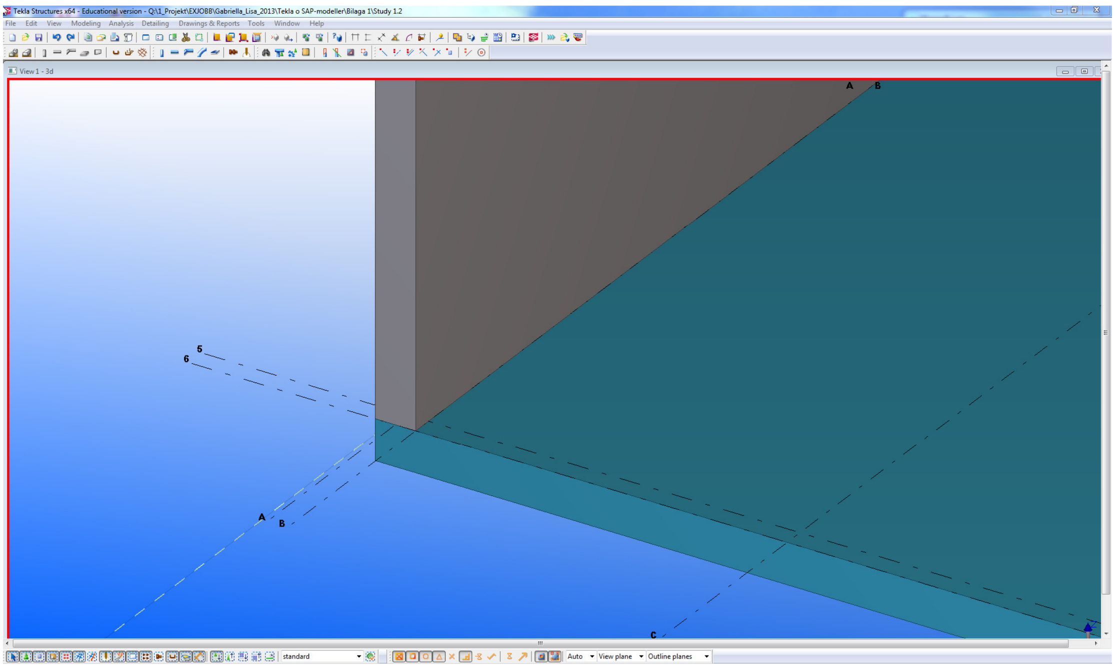


1.2 Export of a panel element in connection to a slab element

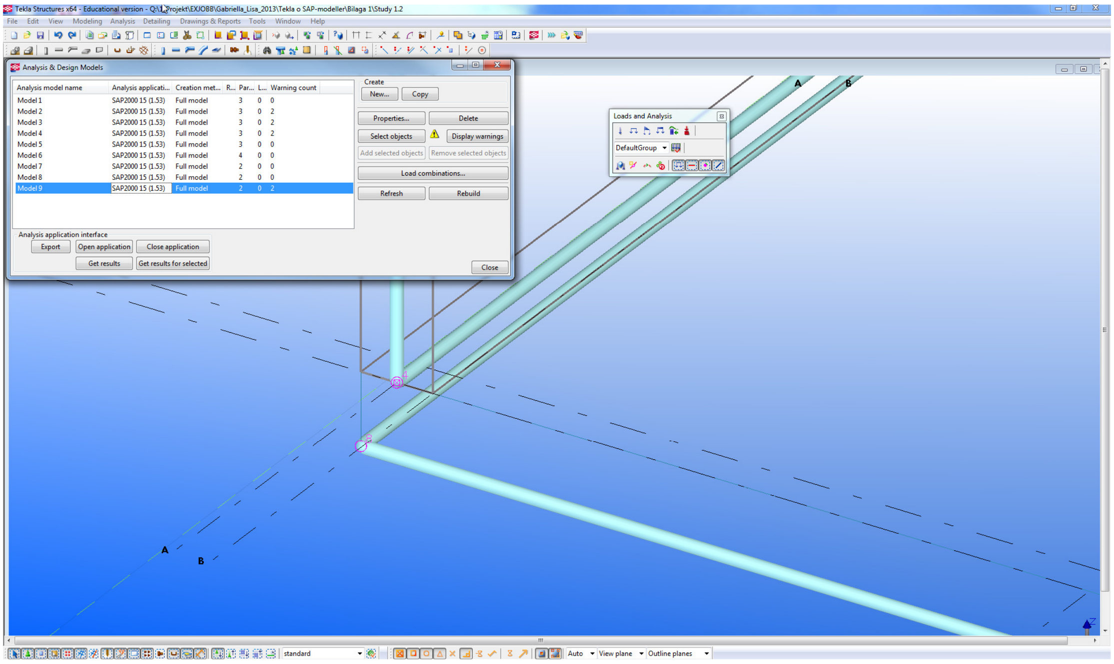
1. A concrete panel and a slab were modelled by using the *Concrete panel*-tool and the *concrete slab* tool. Material properties and thickness of the panel and slab elements was defined.



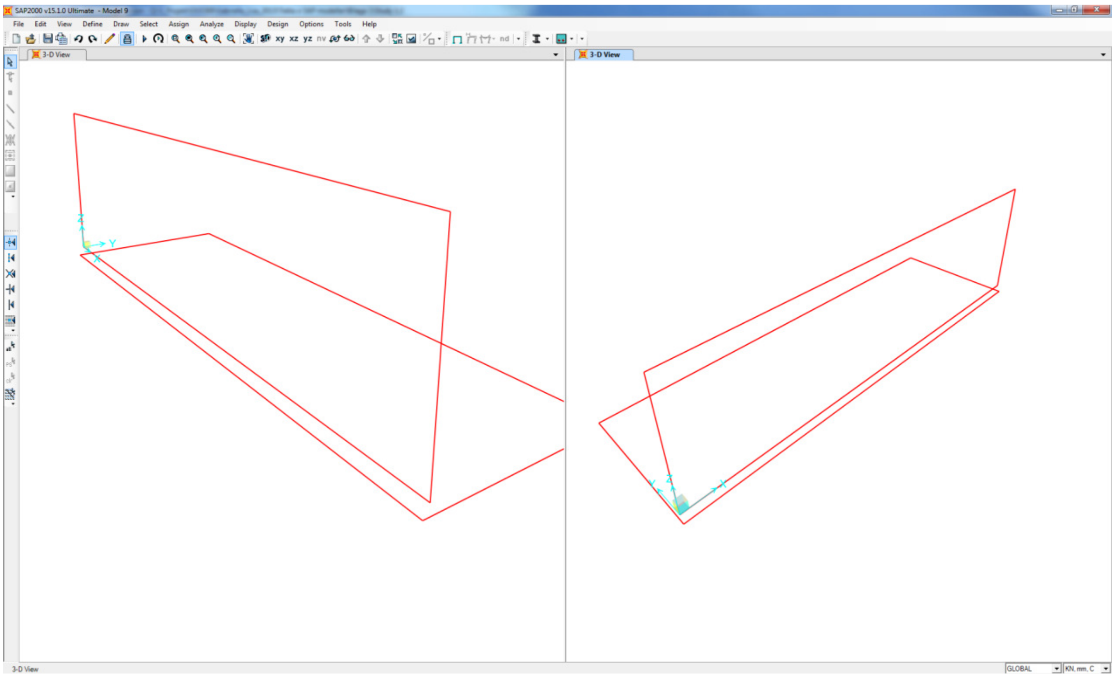
2. The panel was modelled in connection to the surface of the slab.



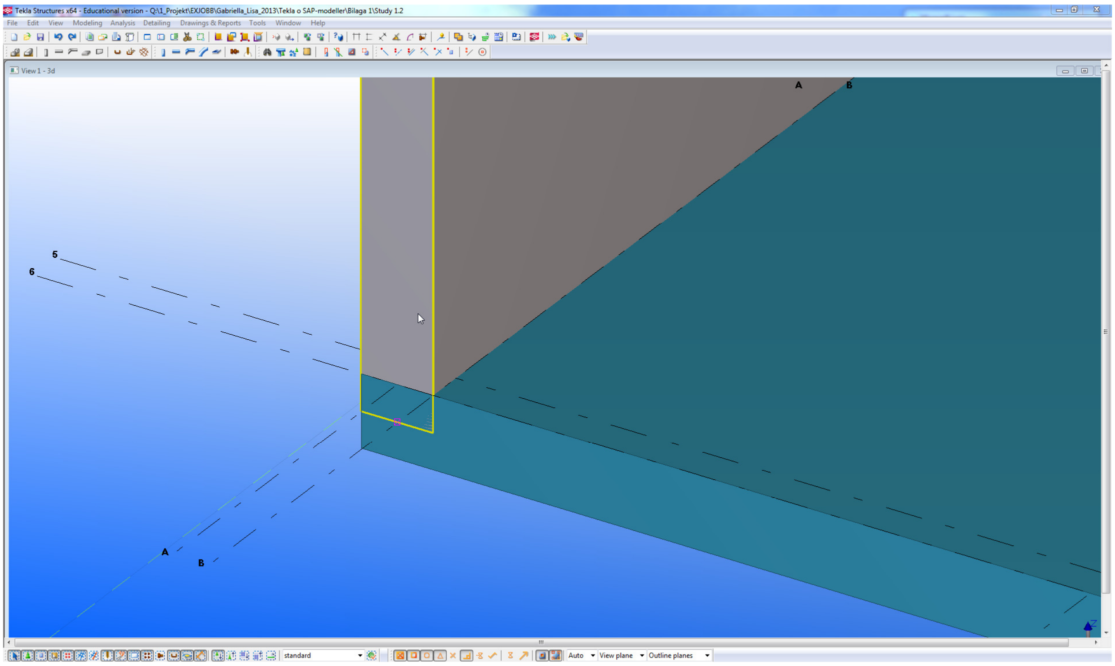
3. The *Analysis & Design model* was created and two separated analysis lines were obtained in TS.



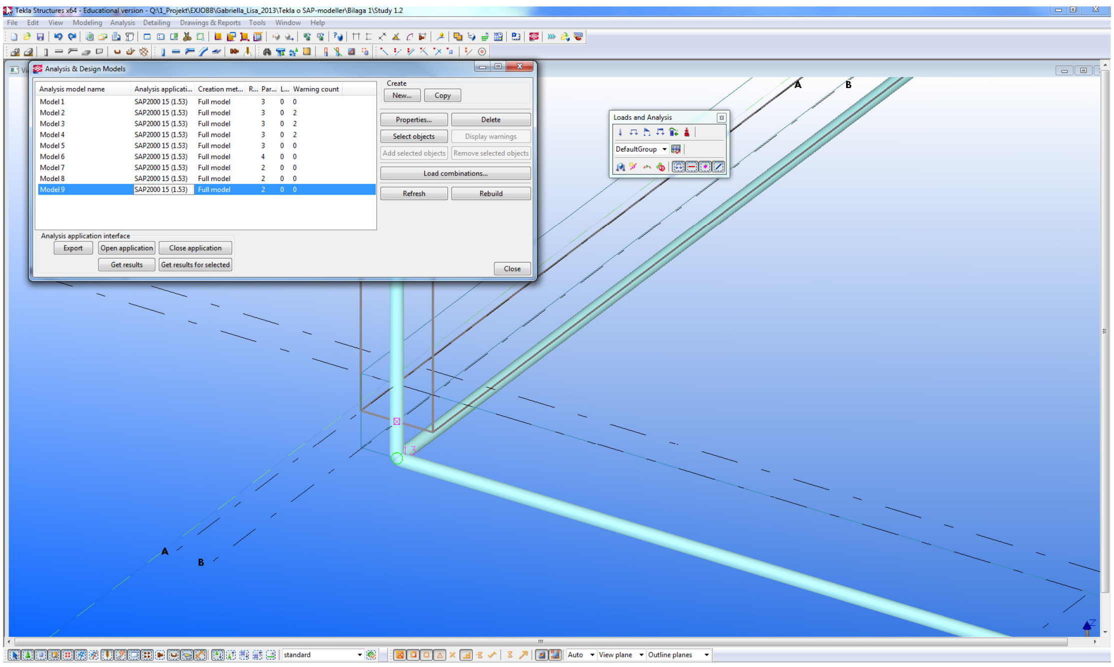
4. The model was exported to SAP and it was obtained that the two elements were exported as two separated elements



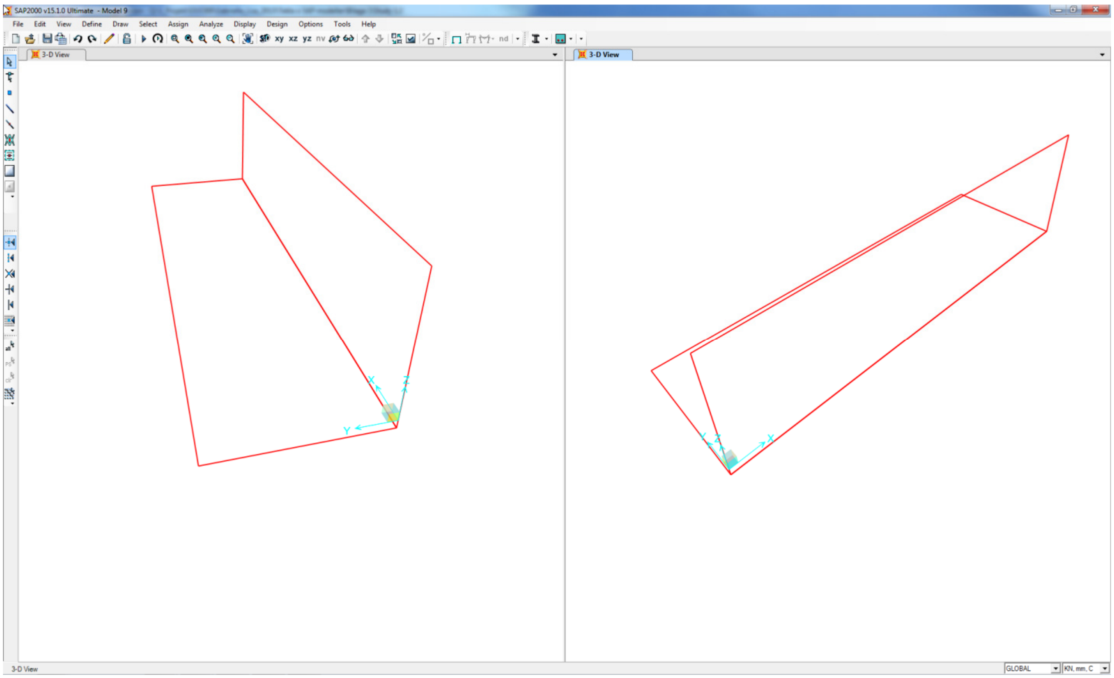
5. The modelling was redone and instead the panel and the slab were connected to each other in their centre lines.



6. An *Analysis & Design model* was again created and it was obtained that the elements shared an analysis line.



7. The model was exported to SAP and the SAP window was opened. The export showed two visually connected elements.

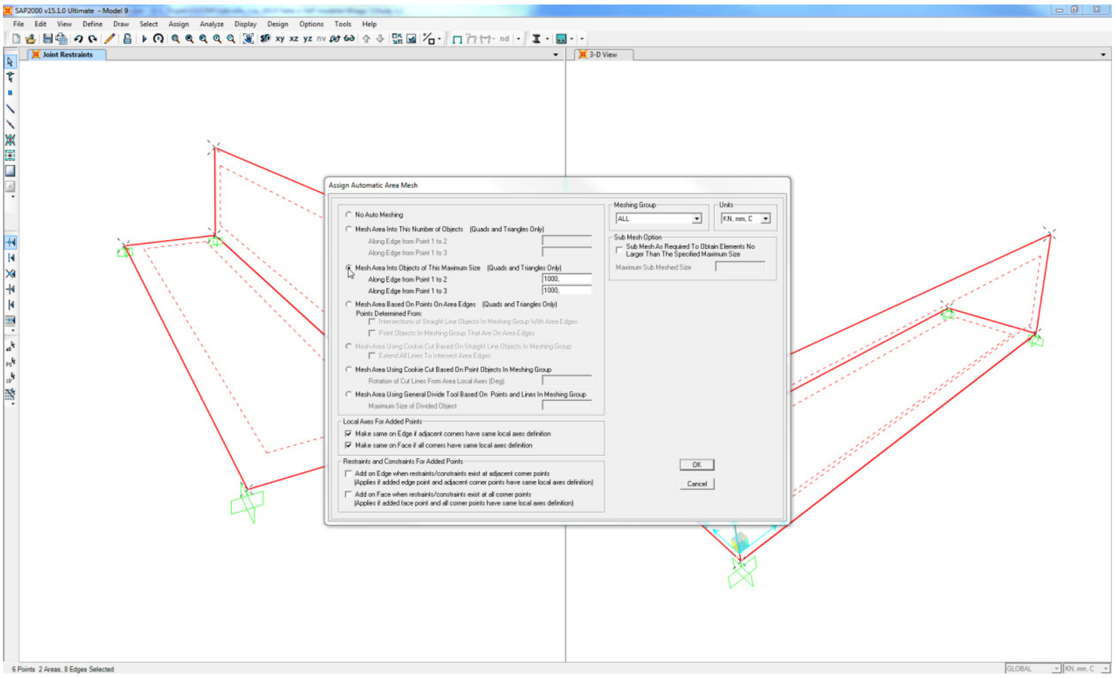


8. To apply a load to the model a new load pattern was created in the *Define Load Pattern* box.

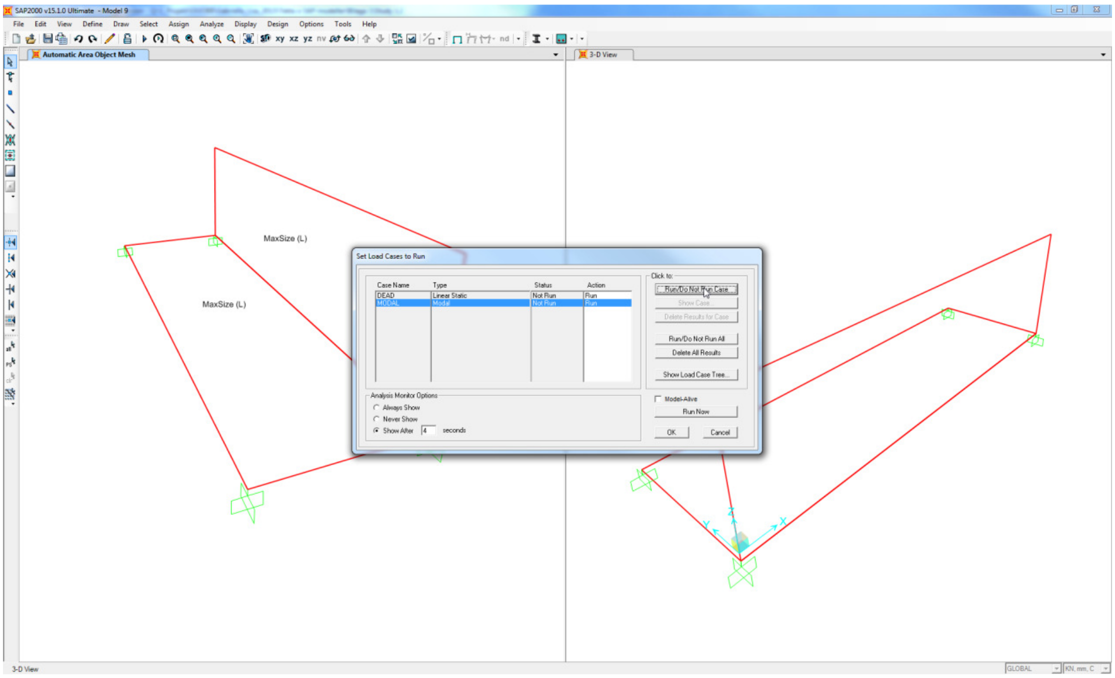
9. An *area uniformed load* was applied to the vertical surface of the slab in the direction of the gravity (z-direction).

10. The corner nodes of the slab were fully restrained.

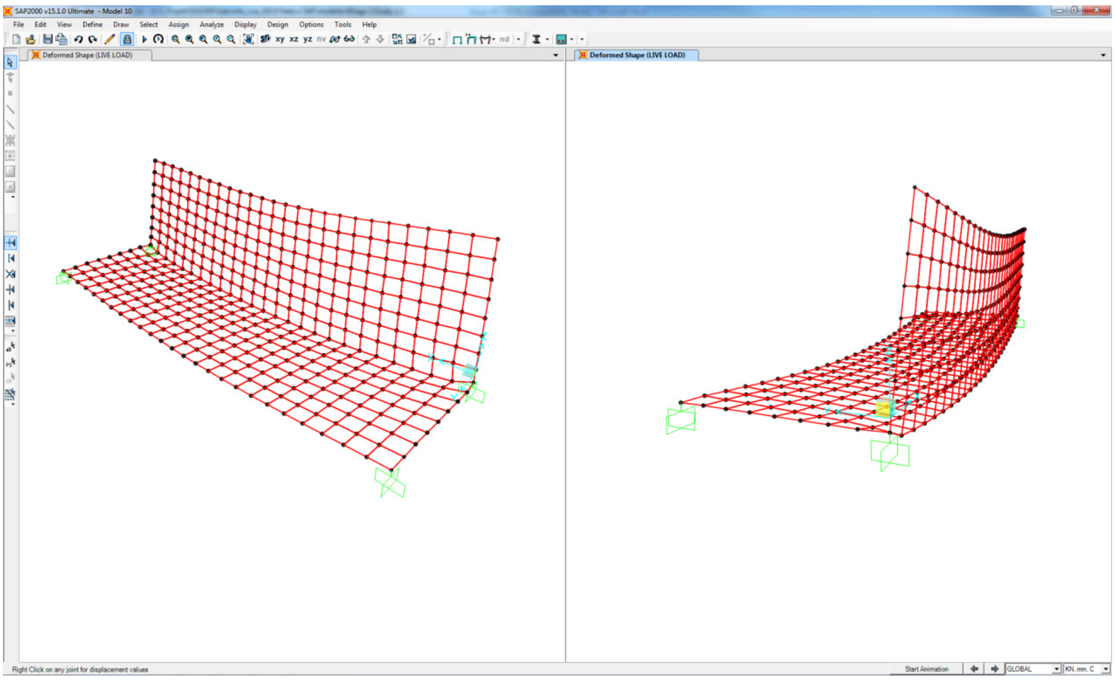
11. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.



12. A linear static analysis was performed by the *Set Load Cases to Run* box. *T*he MODAL case was set to *do not run* in order to save time. This was done for all further studies.

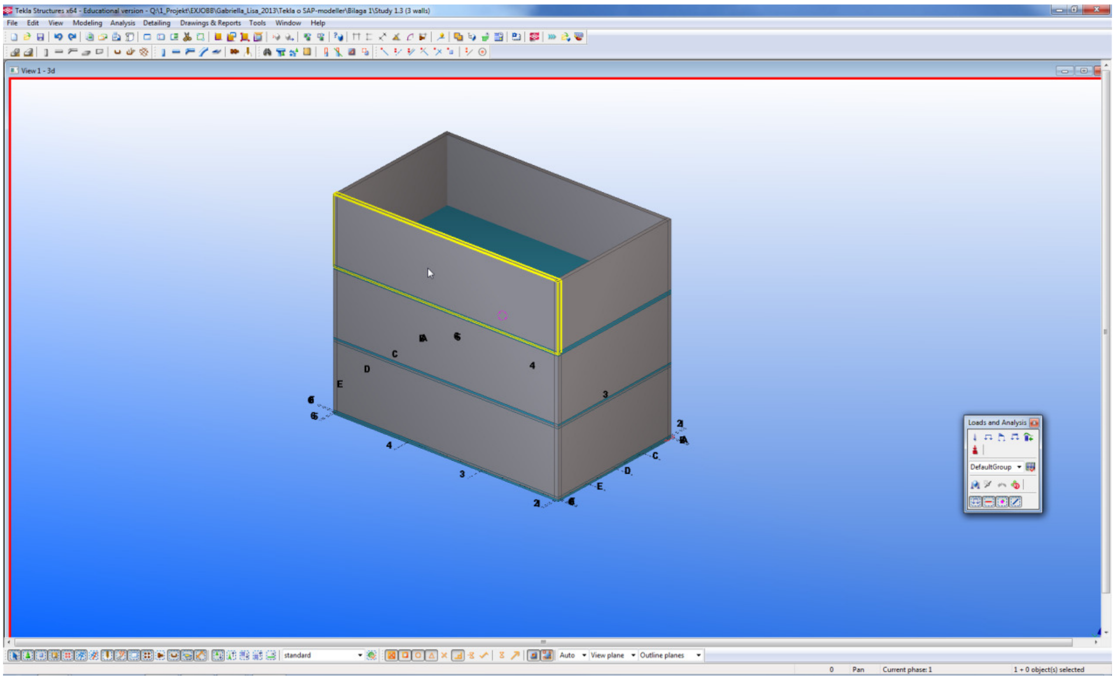


13. The model were meshed and restrains/constrains were generated at the corner of the slab. The slab was influenced only by the applied live load and it could be seen that the elements were deformed together and consequently was the panel and slab connected correctly.

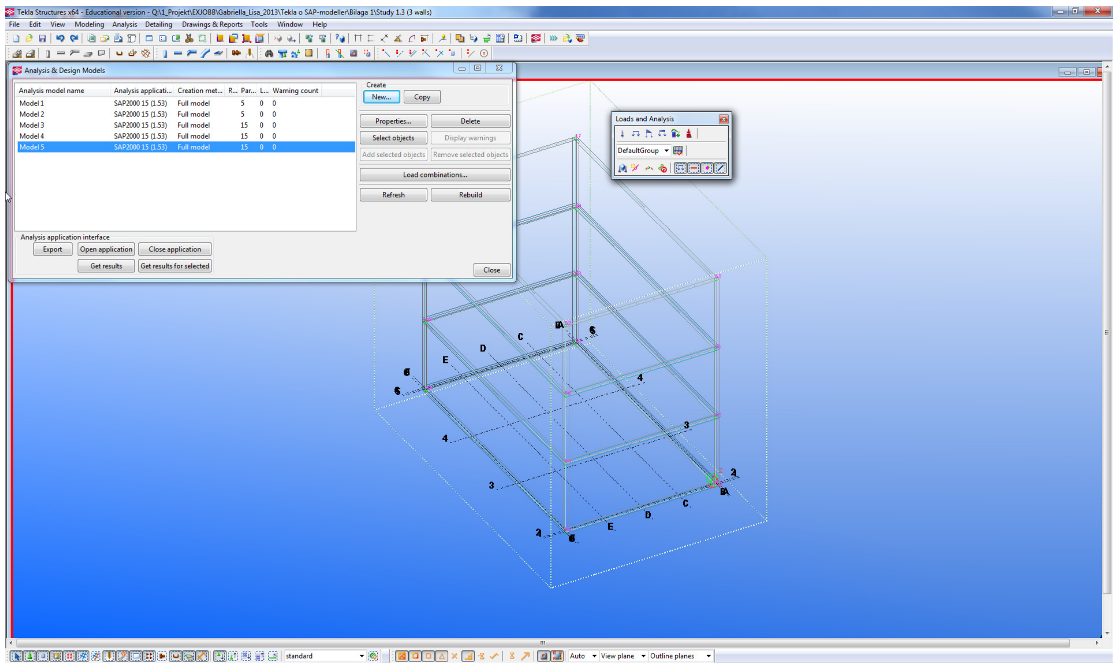


1.3 Export of connected panel and slab elements

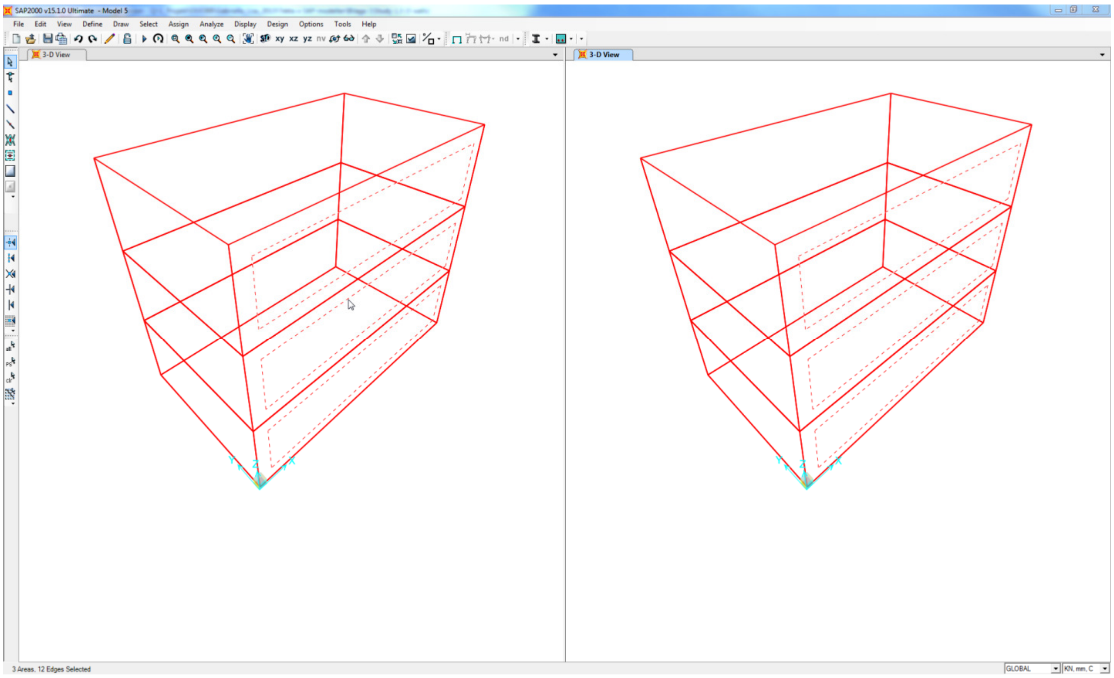
1. The model was created using the *Concrete Panel*- and *Concrete Slab*-tool. Material properties and thicknesses were defined to the elements. Two similar models are created for this case study, the first model was created with one separate panel for each floor and the second with one panel for all floors.



2. The *Analysis & Design model* was created.



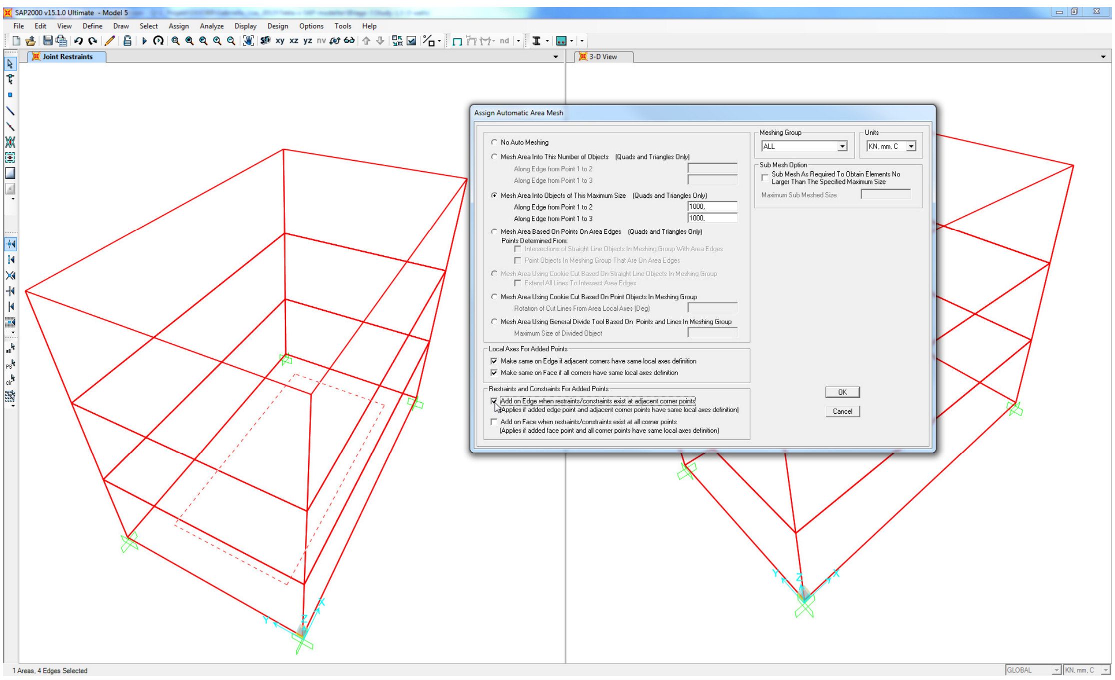
3. The model was exported to SAP and the elements were exported visually correct.



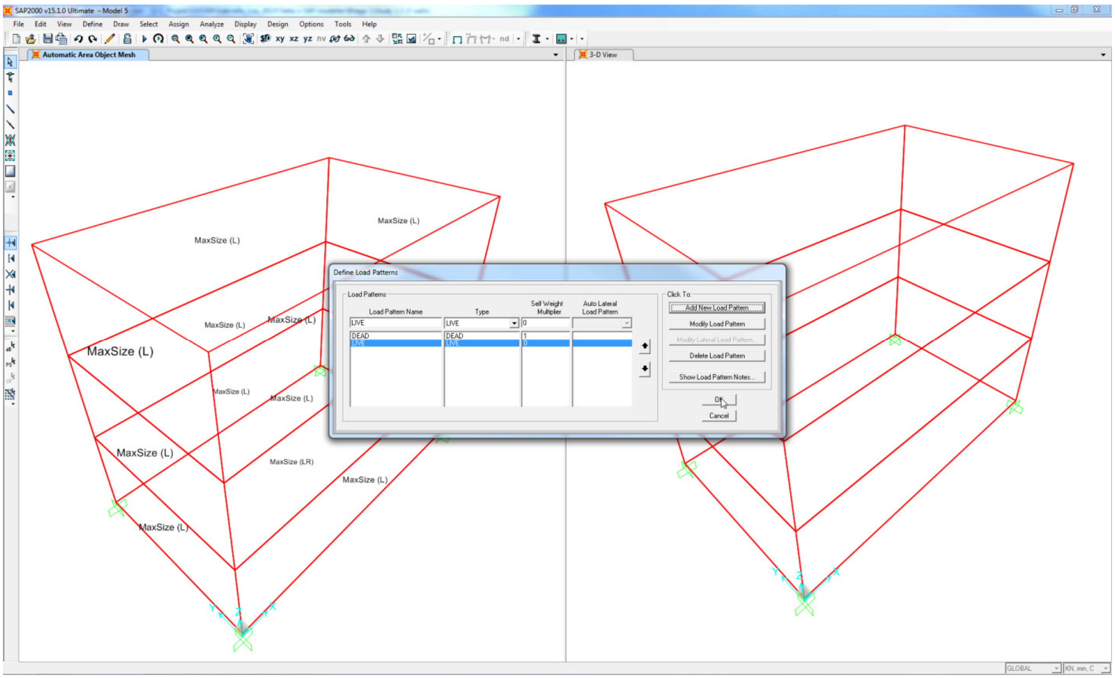
4. The corner nodes of the slab were fully restrained.

5. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

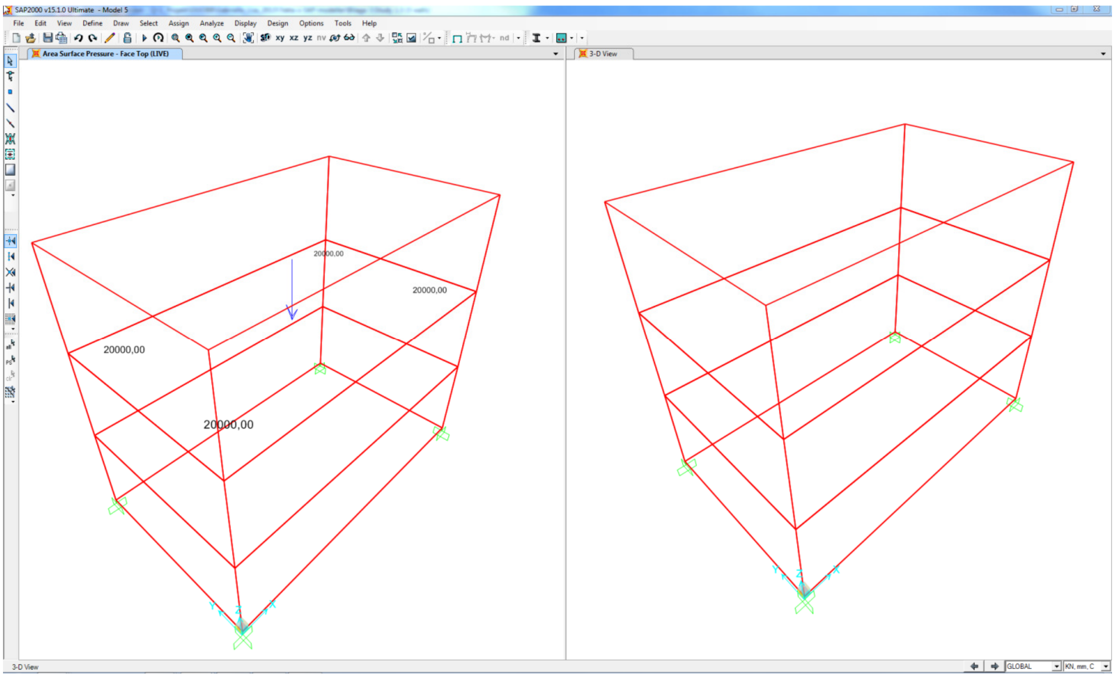
6. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*



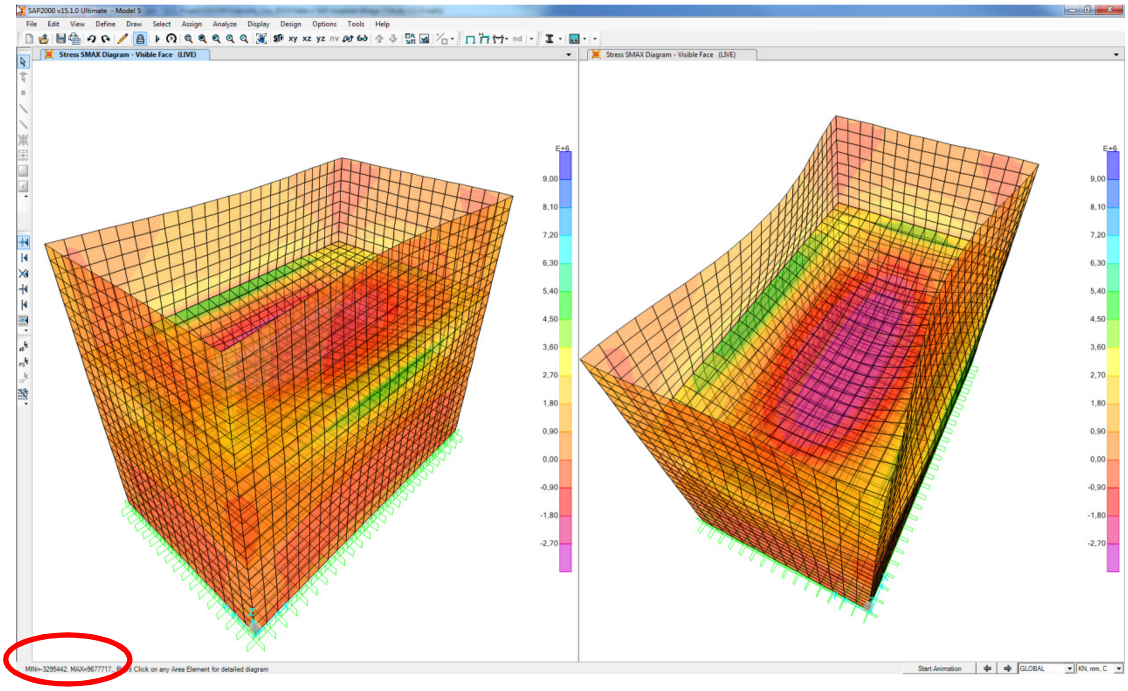
7. To apply a load to the model a new load pattern was created in the *Define Load Pattern* box.



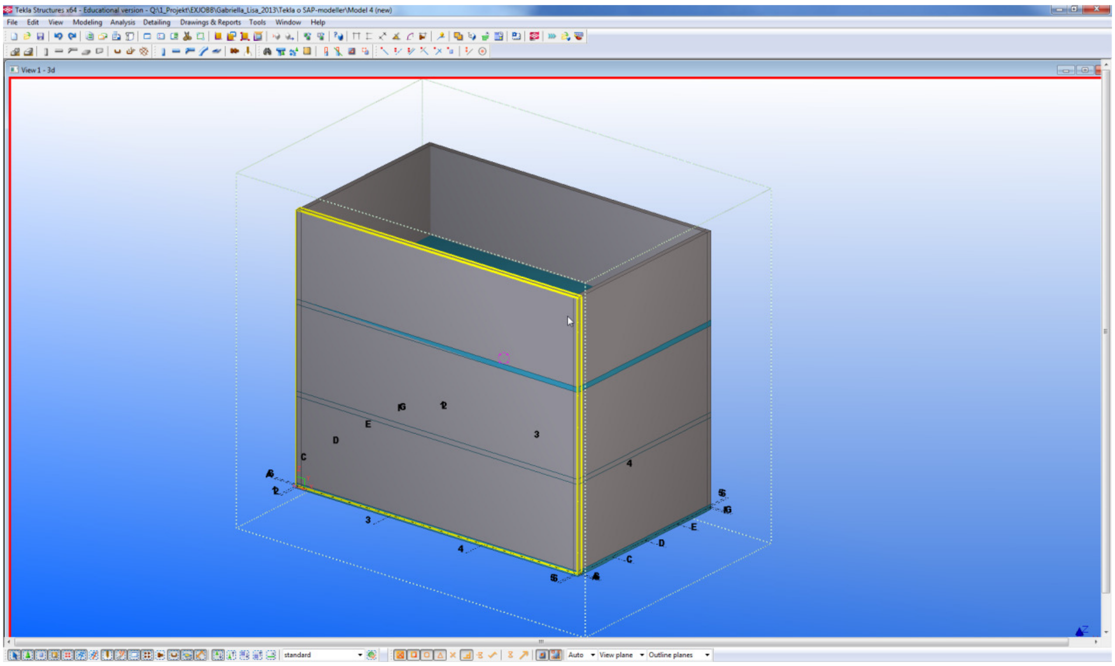
8. A *surface load* in the direction of the gravity (z-direction) was applied to the top slab of the model.



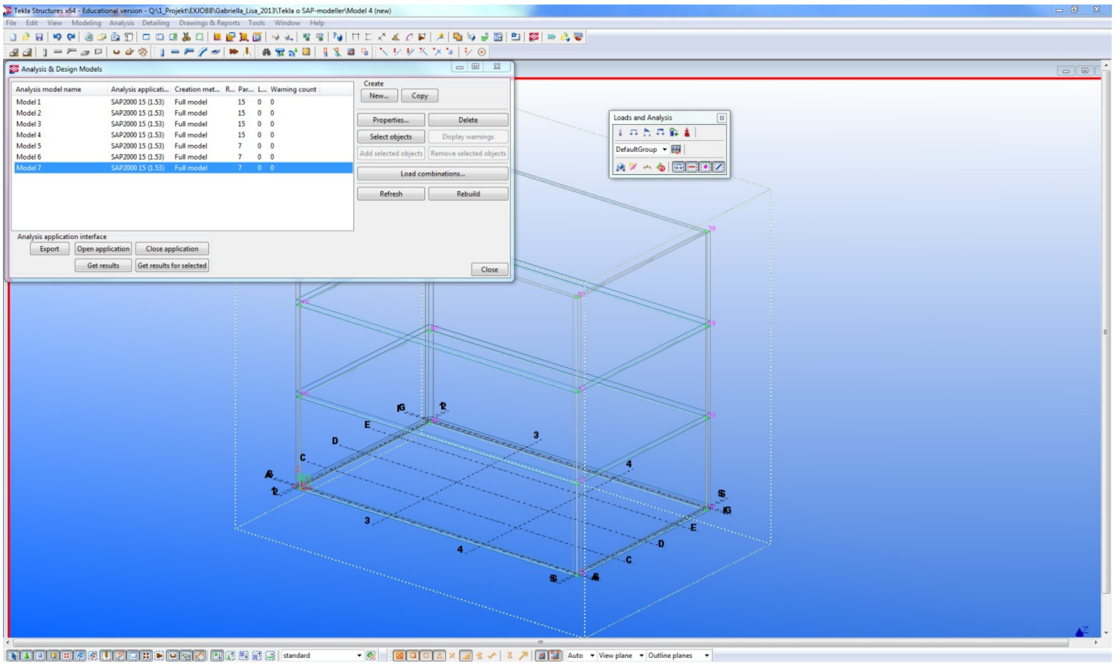
9. An analysis of the model was performed and the stress SMAX diagram based on the live load was displayed. The maximum- and minimum value of the maximum stress was displayed in the bottom corner of the window.



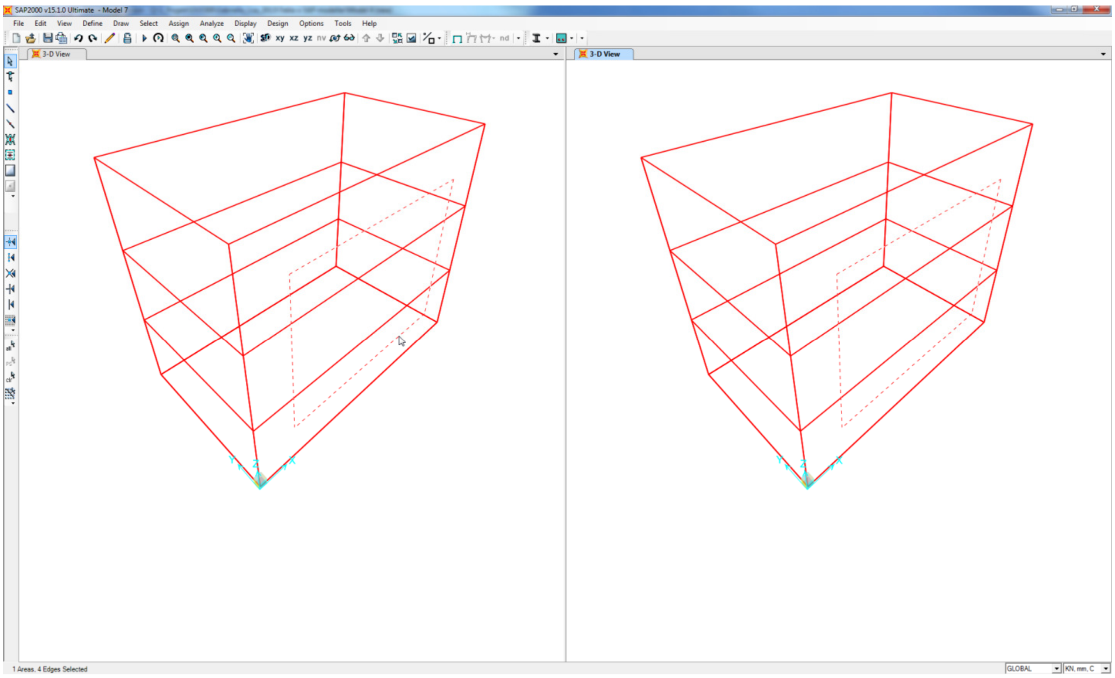
10. For the second case, the model was created with one panel element along all three floors otherwise the same modelling technique was used as for the previous model.



11. The *Analysis & Design model* was created without any *warning counts*.



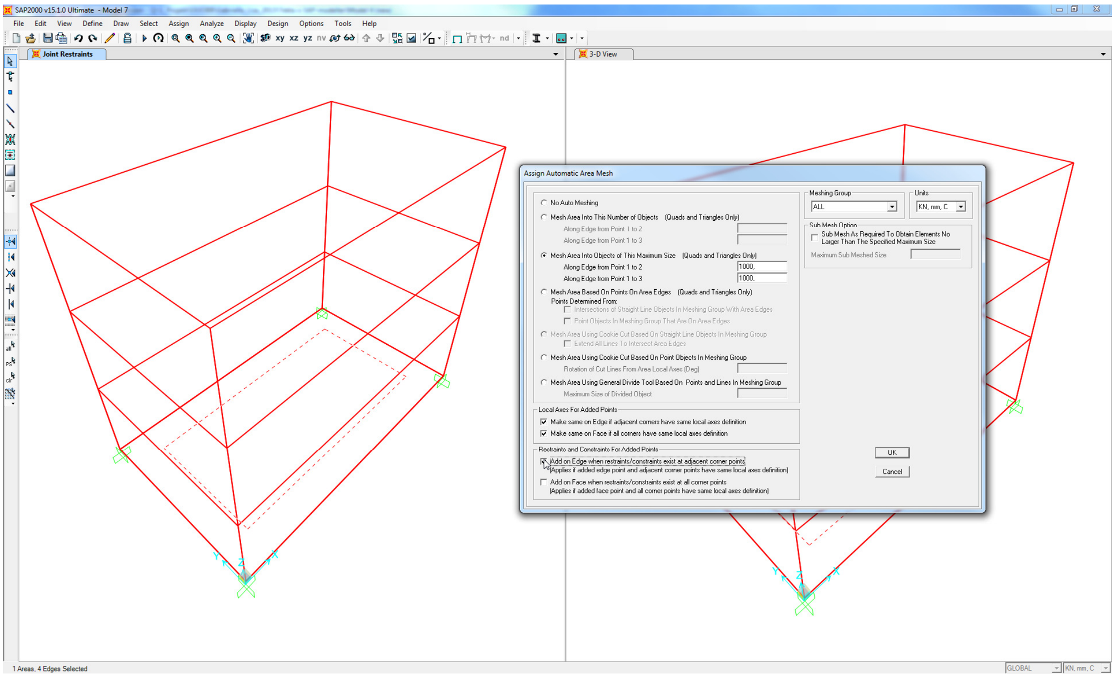
12. The model was exported to SAP. The dimensions were visually exported correct.



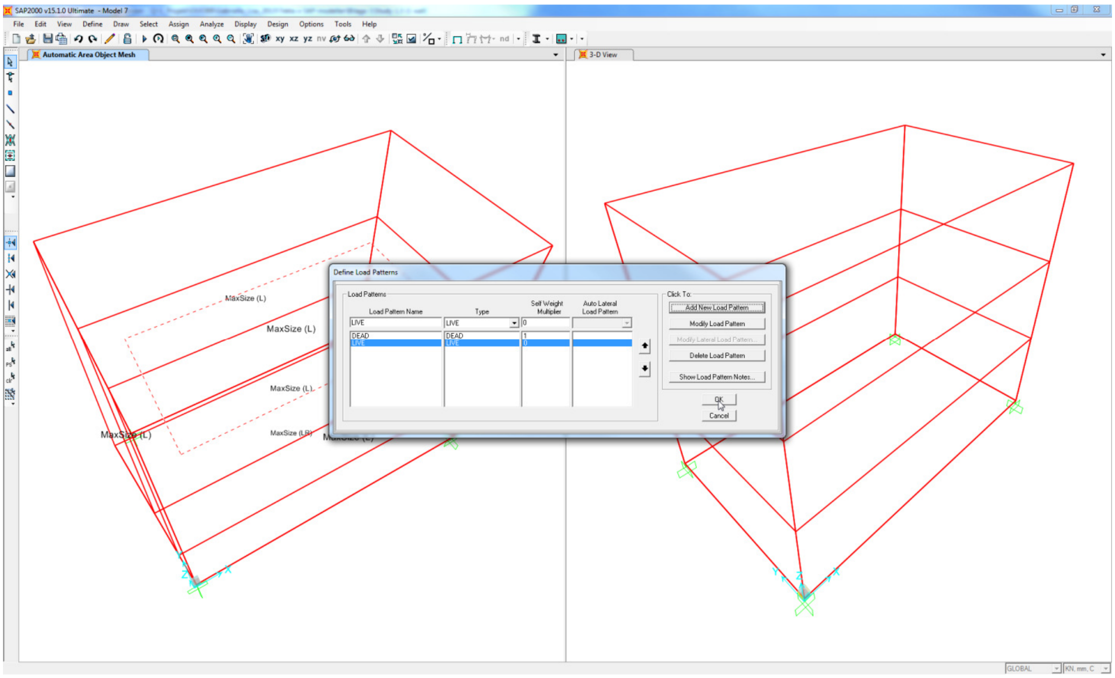
13. The corner nodes of the slab were fully restrained.

14. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

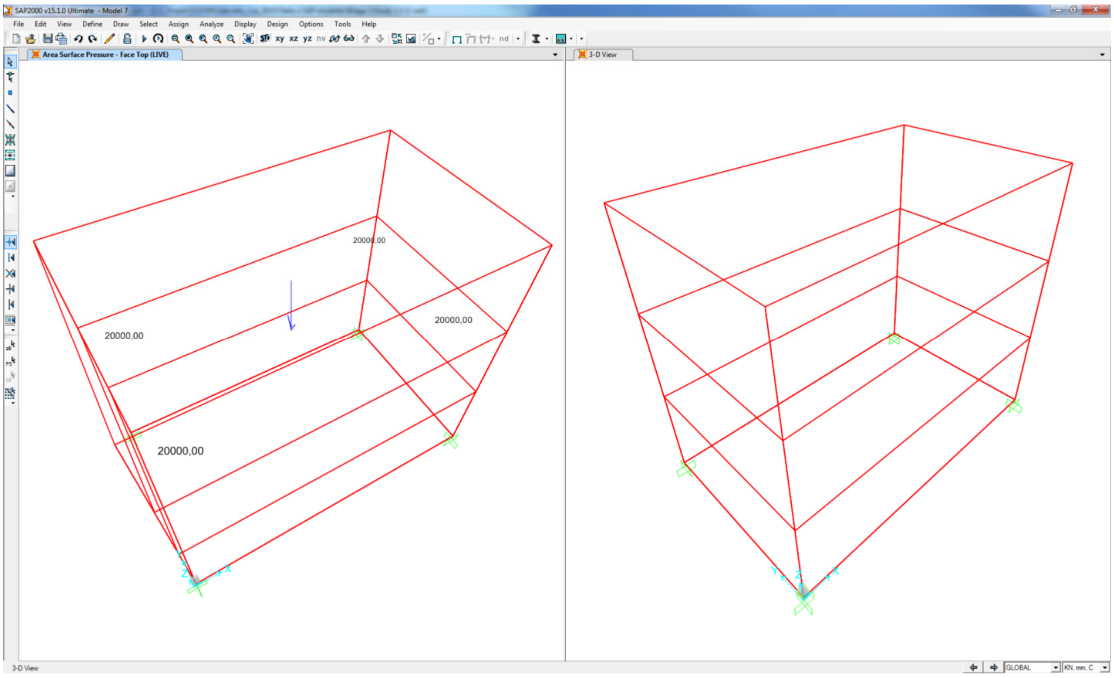
15. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*



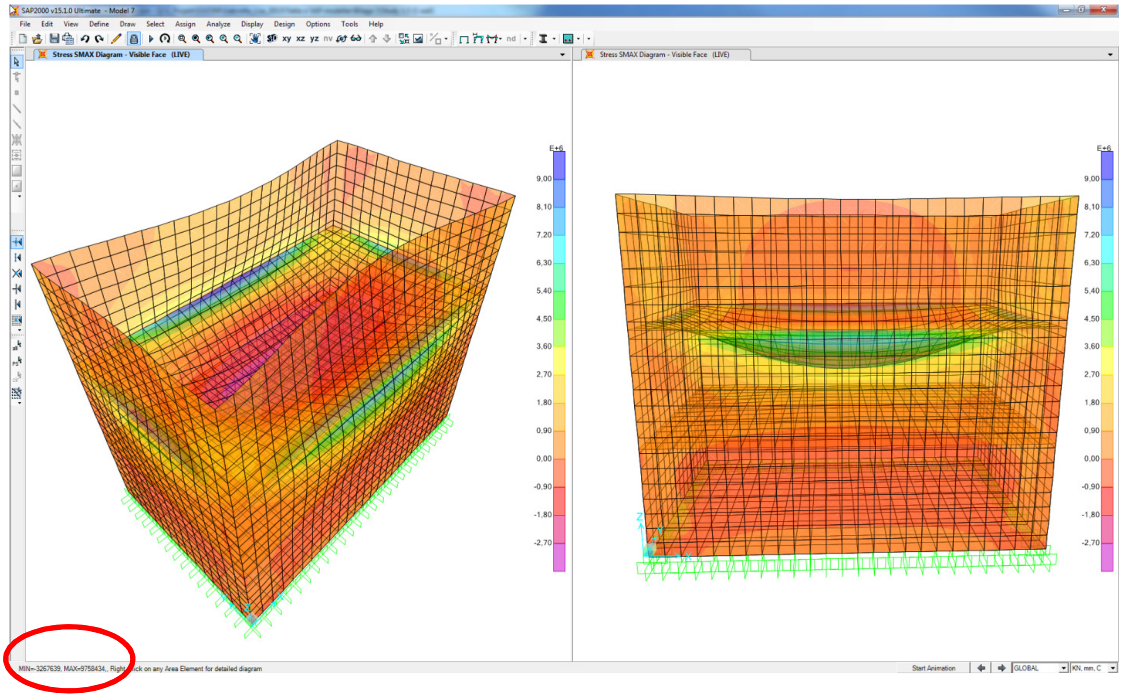
16. To apply a load to the model a new load pattern was created by the *Add New Load Pattern* button in the *Define Load Pattern* box.



17. A *surface load* in the direction of the gravity (z-direction) was applied to the top slab of the model.



18. An analysis of the model was performed and the stress SMAX was displayed.



2 Export of openings in panel and slab elements

The purpose of this study was to identify feasibilities and limitations of the export from TS to SAP of panel and slab elements containing openings.

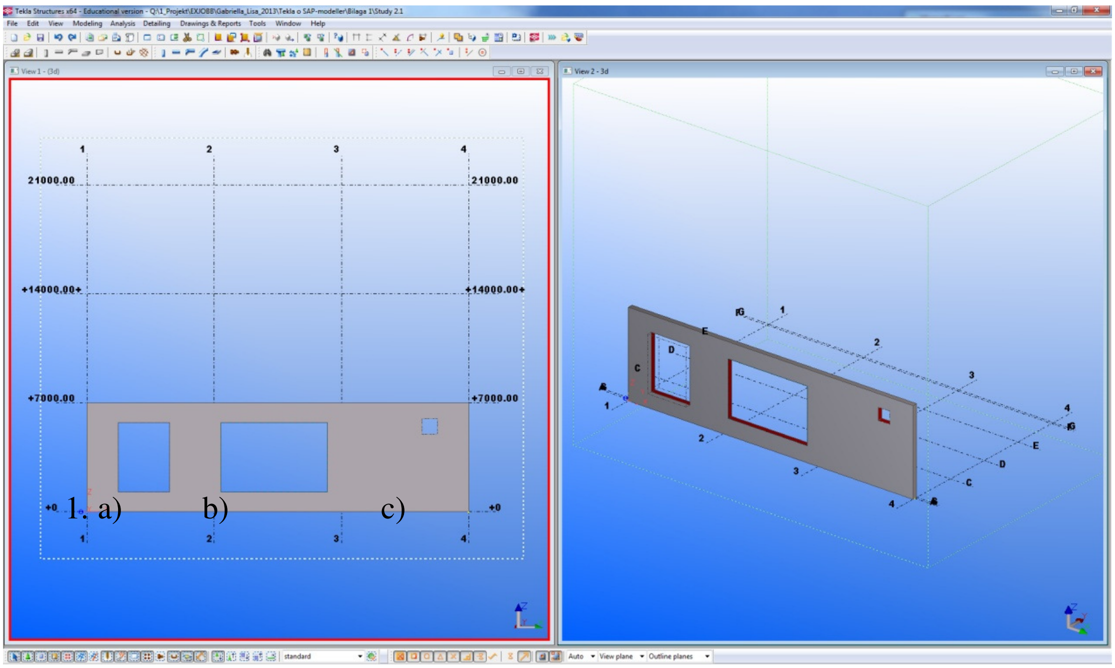
The case study was divided into seven studies:

- Export of rectangular openings within a panel element
- Export of several panels elements creating an opening
- Export of rectangular openings at the edge of a panel element
- Export of panel and slab elements with rectangular openings
- Export of a circular opening within a panel element
- Export of a circular opening at the edge of a panel element
- Export of rectangular openings in a slab element

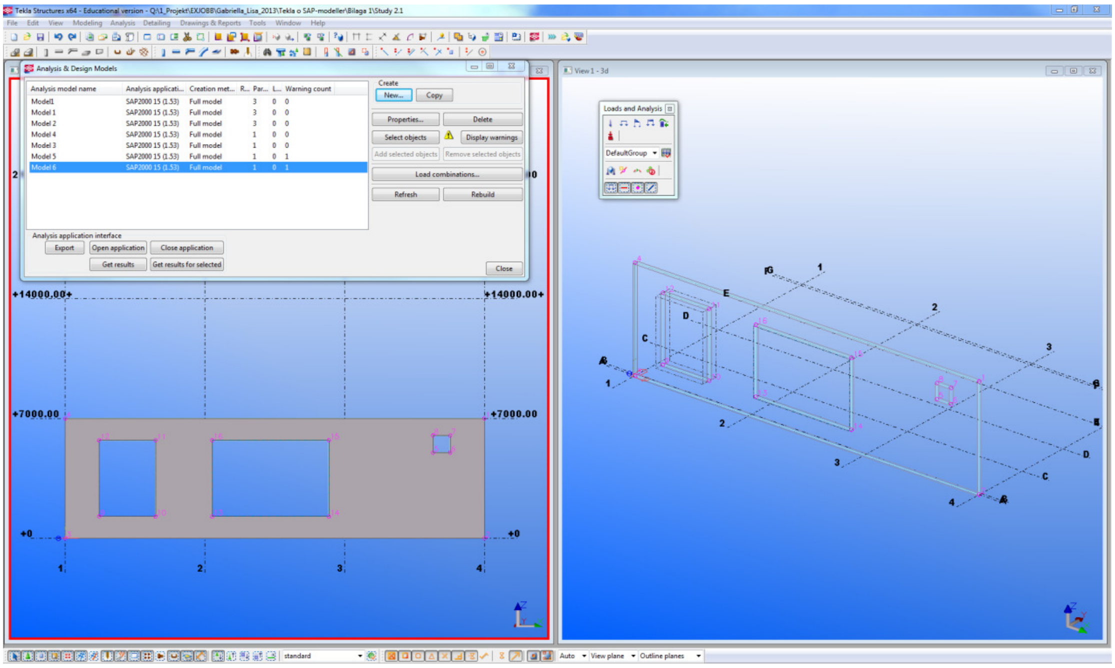
2.1 Export of rectangular openings within a panel element

1. The model was created using *Concrete panel* and the openings was created using following modelling techniques:

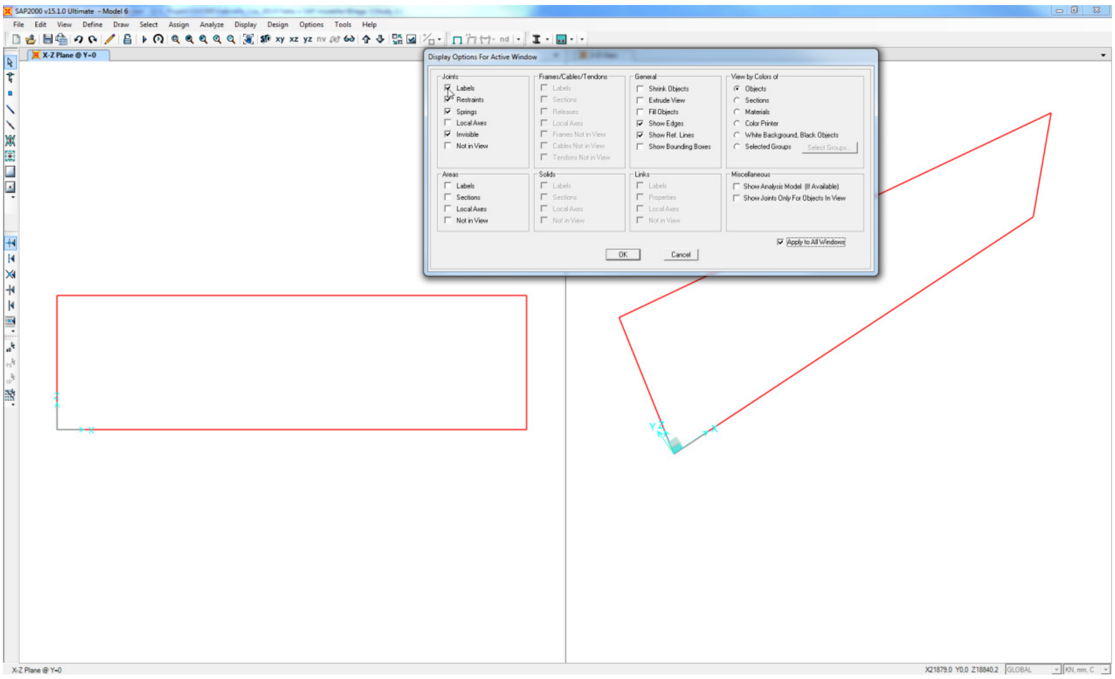
   a) Cut part with another part
   b) Cut part with polygon
   c) Cut part with component ("Hole generation 32")



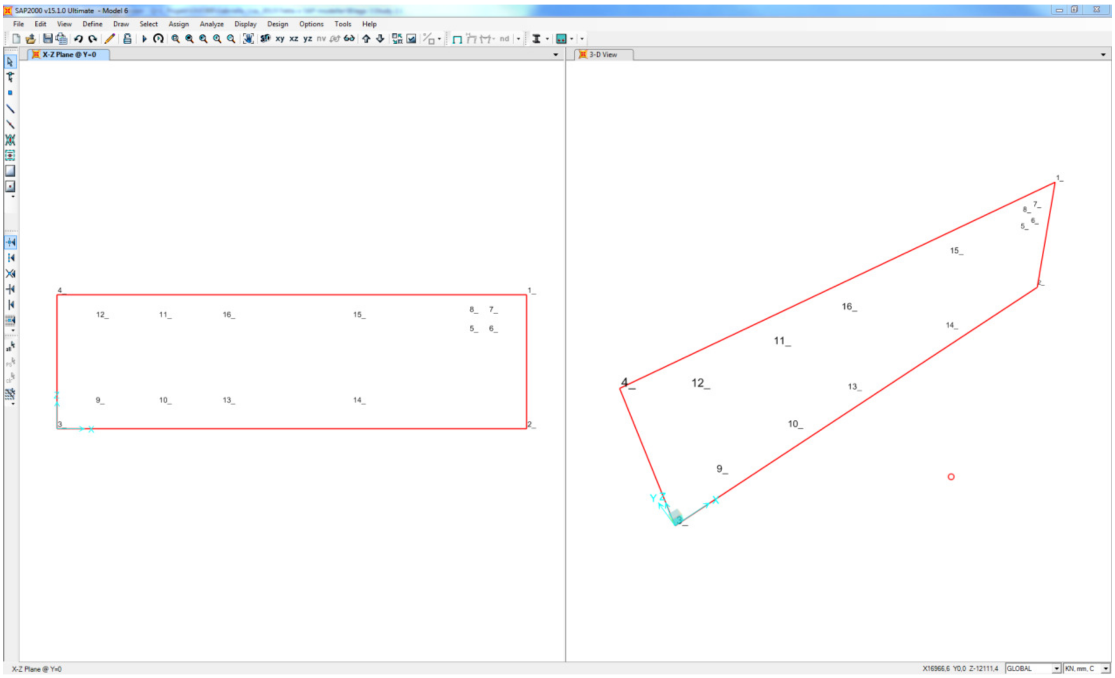
2. The *Analysis & design model* was created and analysis lines with a number of nodes were created both for the panel and for the openings.



3. The model was exported to SAP using the *Export*-link. The panel was exported without any openings. In order to see if the nodes were exported instead the *Labels* of the elements were displayed by going to the *Display Options For Active Window*.



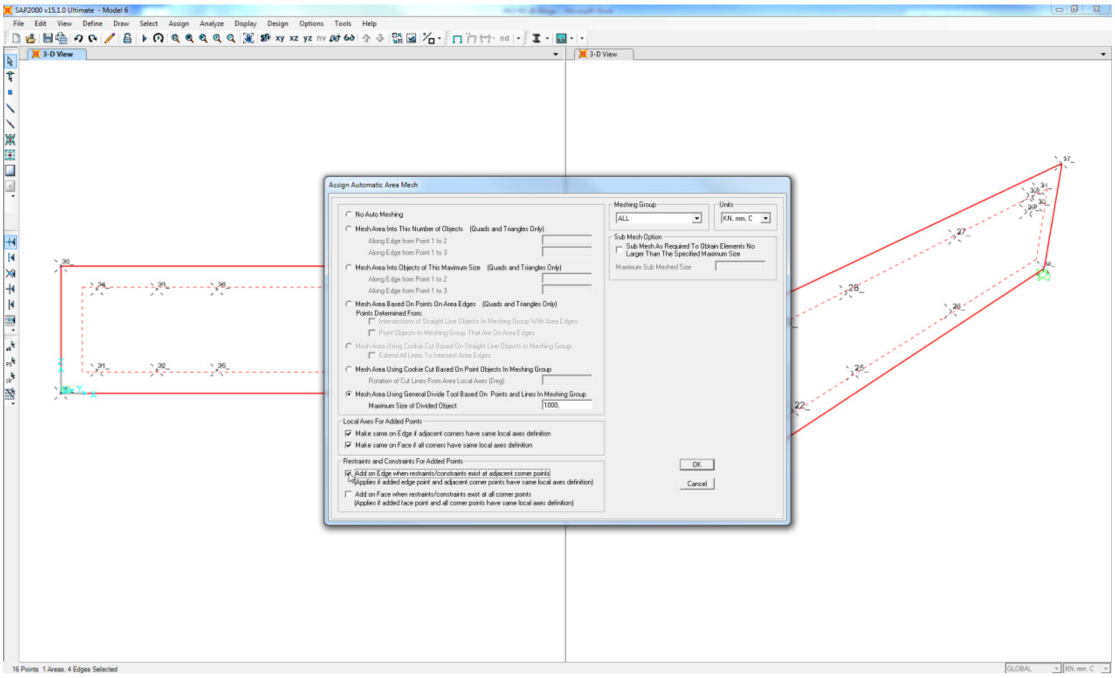
4. The nodes of all openings were exported and the nodes were given the same numbering as in TS.



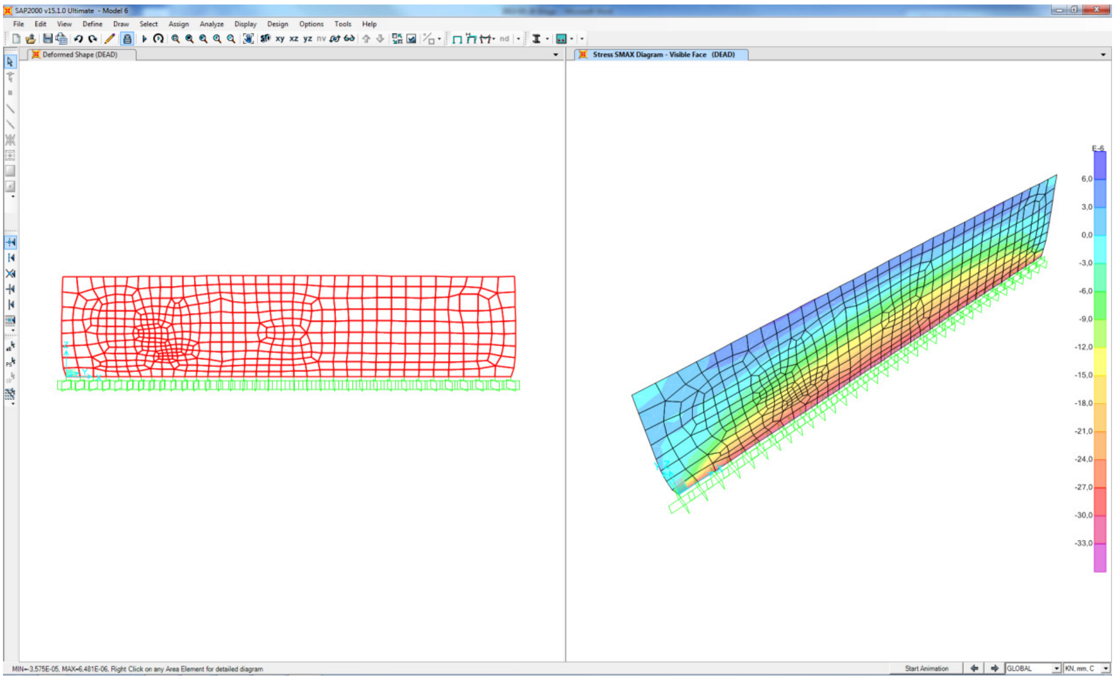
5. The bottom corner nodes of the panel were fully restrained.

6. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Using General Divide Tools Based On Points and Lines In Meshing Group.* The maximum size of divided objects chosen by the program was kept.

7. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*

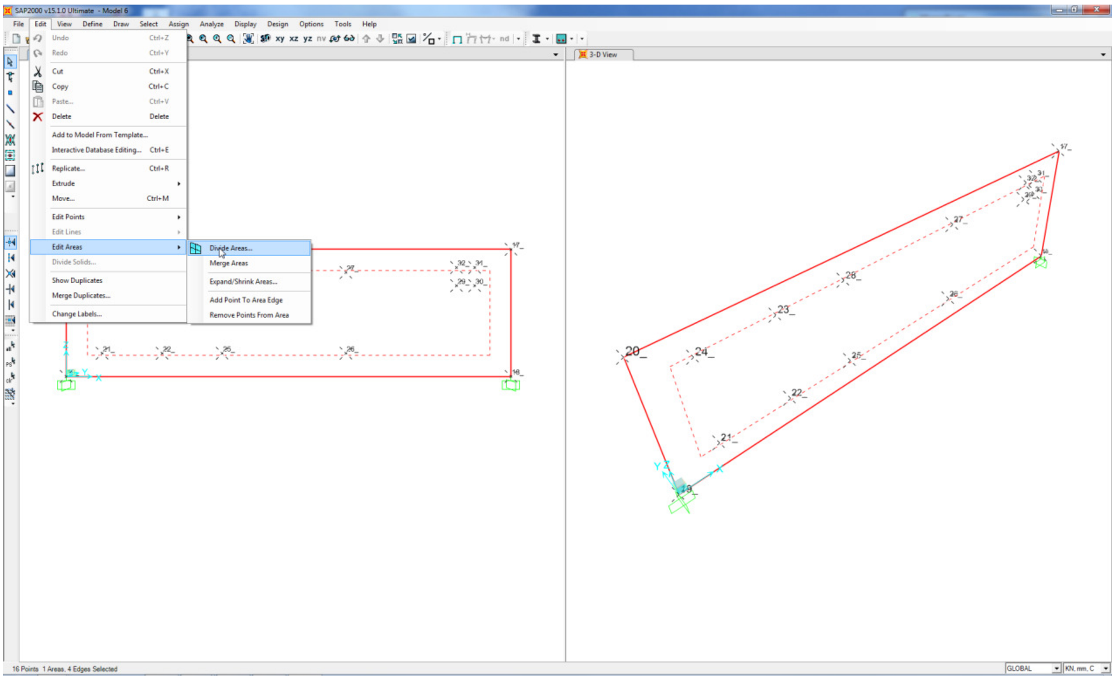


8. An analysis was performed. The generated mesh was influenced by the nodes of the openings.

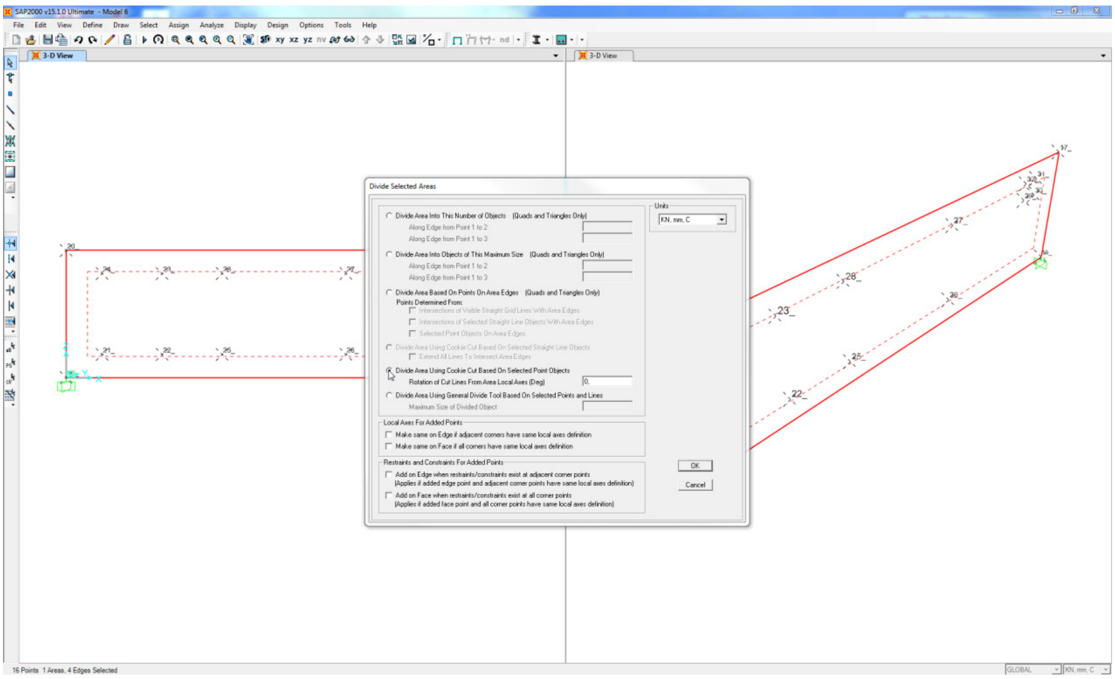


9. The model was unlocked

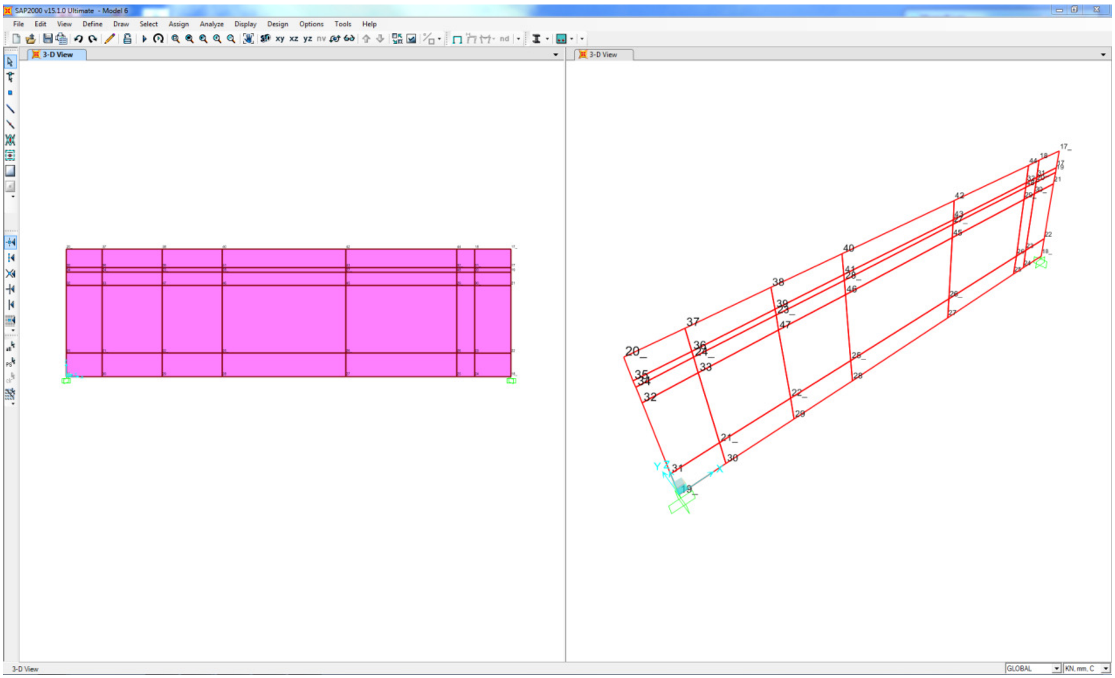
10. The panel was divided into areas in between the nodes.



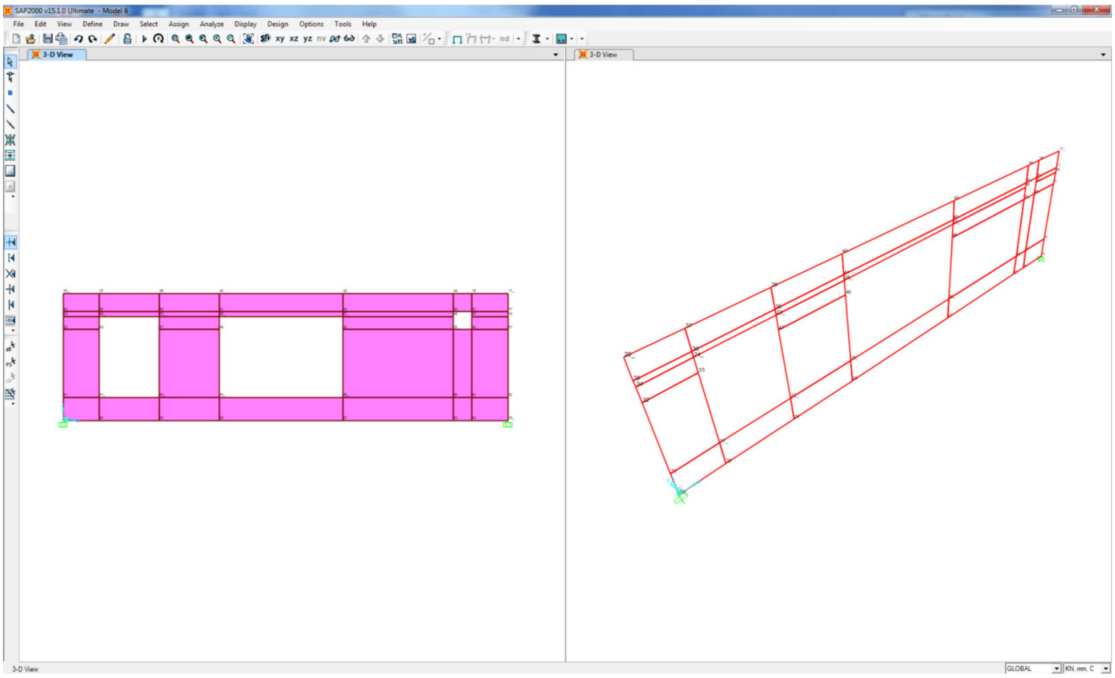
11. In the *Divide Selected Areas* box the dividing choice *Divide Area Using Cookie Cut Based On Selected Point Objects* was chosen.



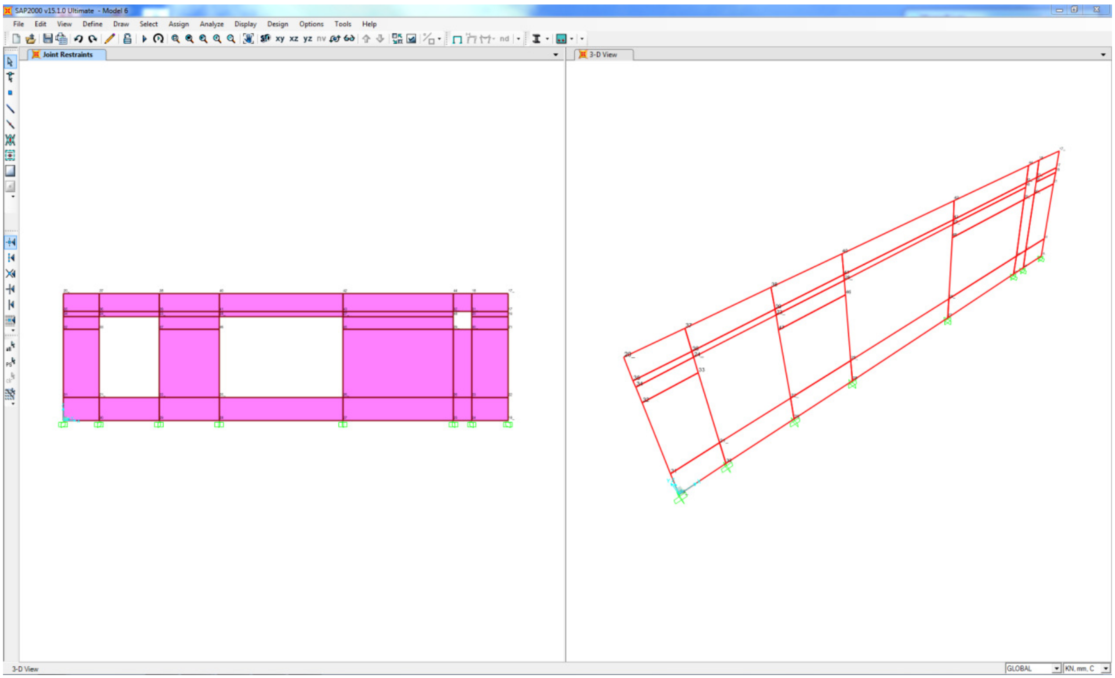
12. The model was divided into smaller areas based on the nodes inside the model.



13. The number of the nodes of the opening was localised by comparing with numbers in the analysis model in TS. The area in between the nodes for each opening was selecting by marking the area and pressing *delete*.

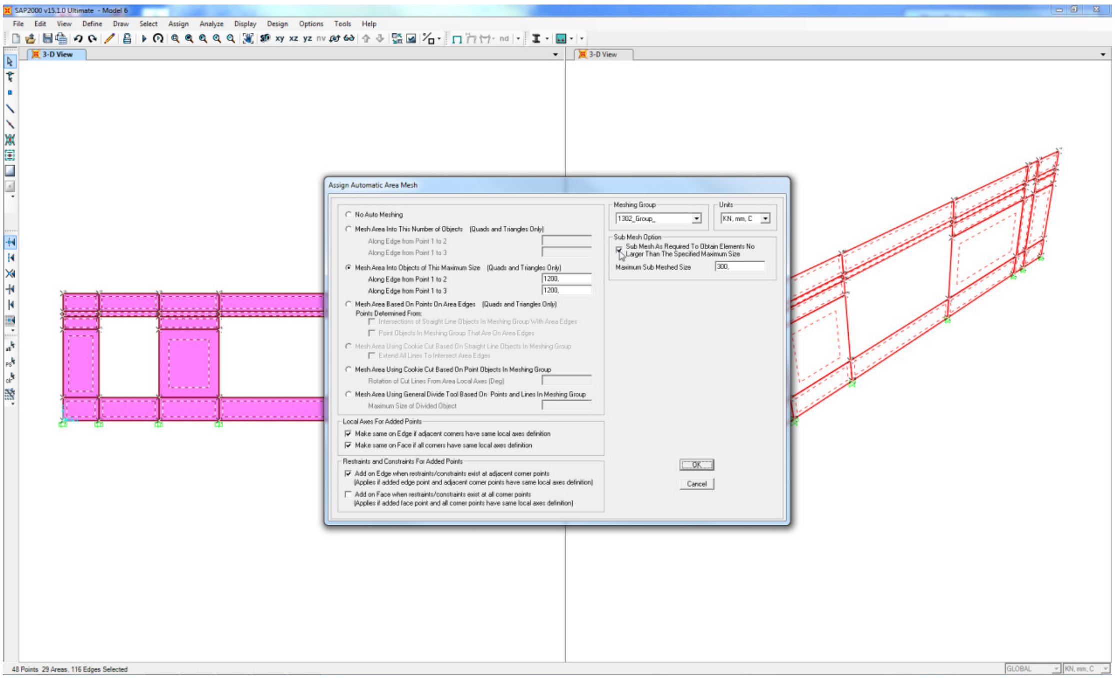


14. All nodes along the bottom edge of the slab were fully restrained.

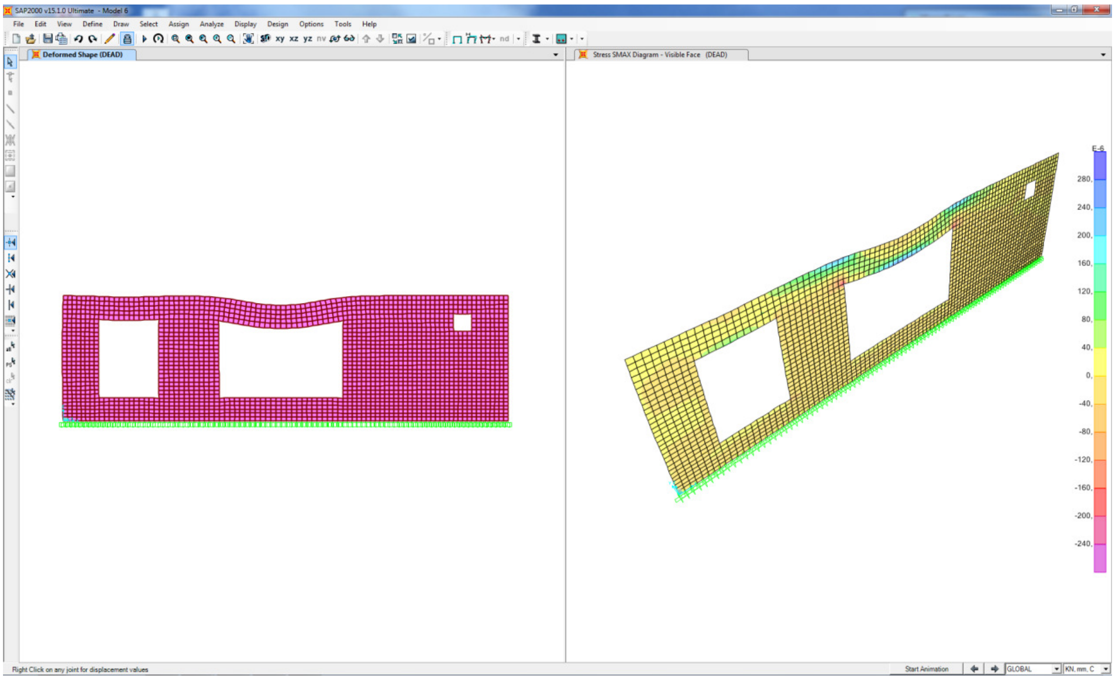


15. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *No Auto Mesh.* The meshing option was changed to *Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept. In order to get a sufficient fine mesh the option *Sub Mesh As Required To Obtain Elements No Larger Than The Specified Maximum Size* was used and a maximum size of the elements was specified.

16. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*

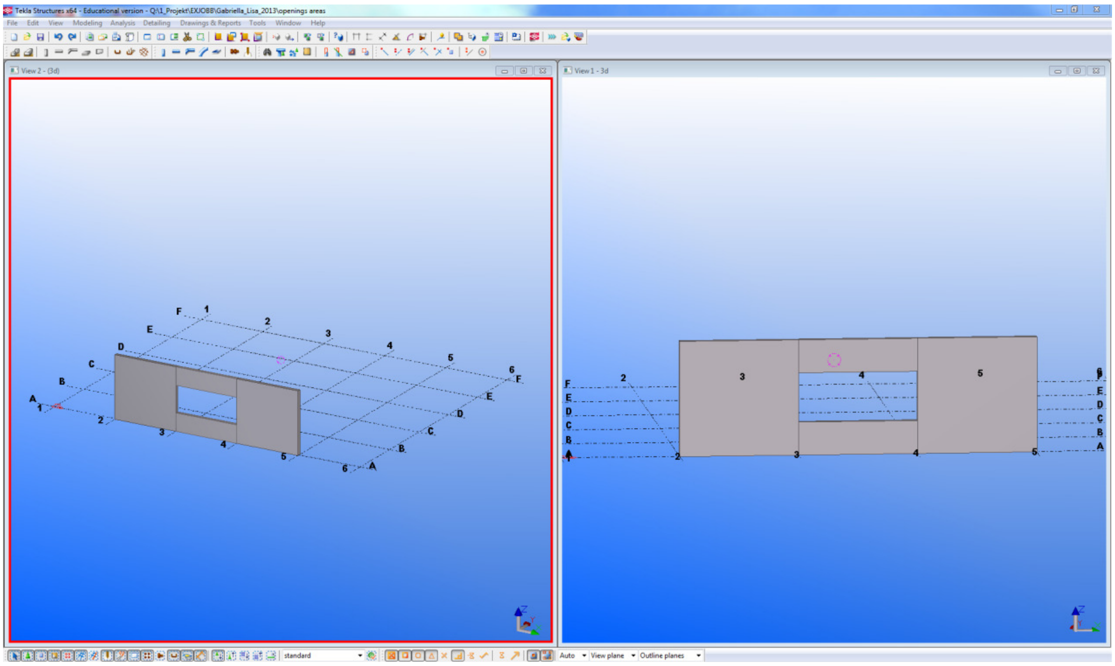


17. An analysis was performed and the response of the panel containing openings was as expected.

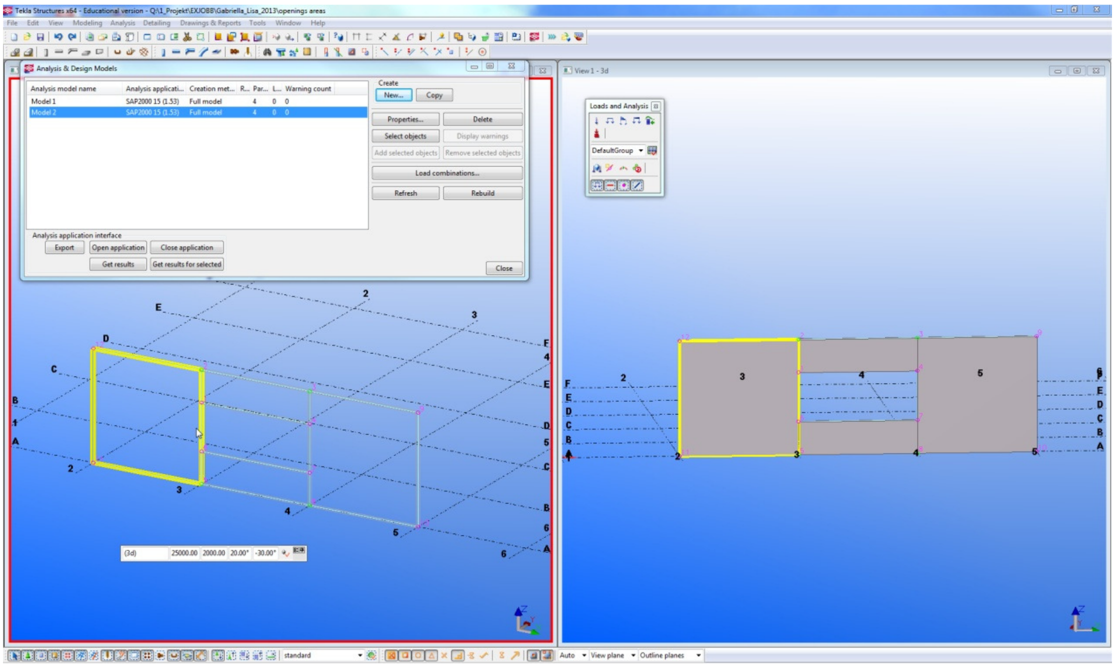


2.2 Export of several panels elements creating an opening

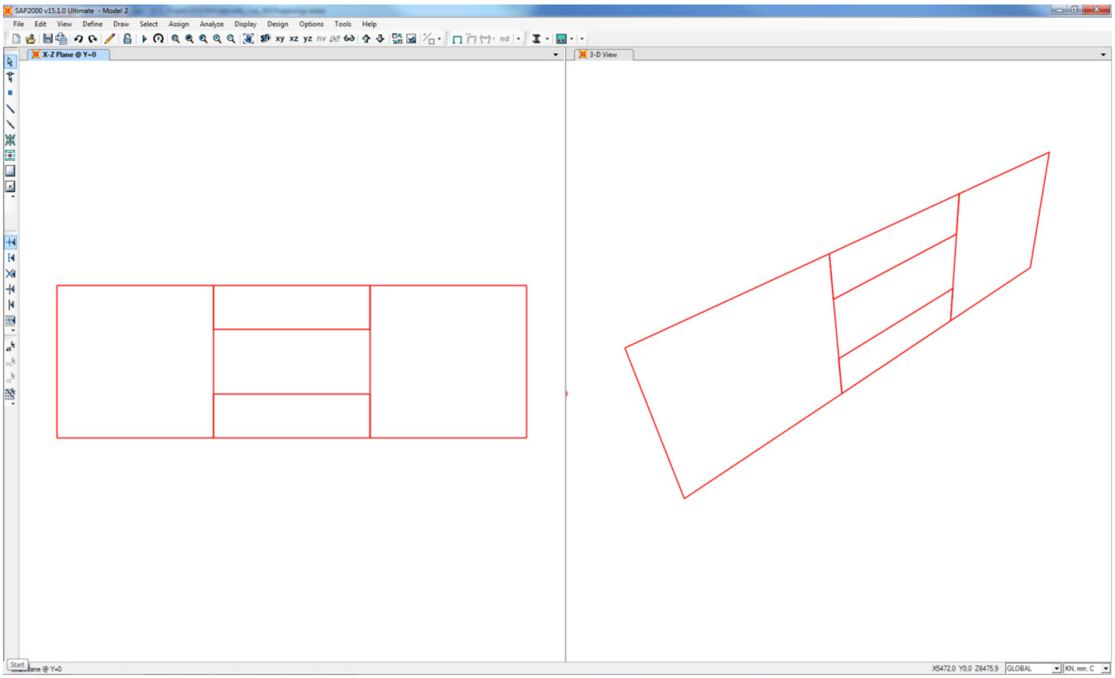
1. The model was created using *concrete panel*-tool. The panels were placed resulting in an opening was created within the object.



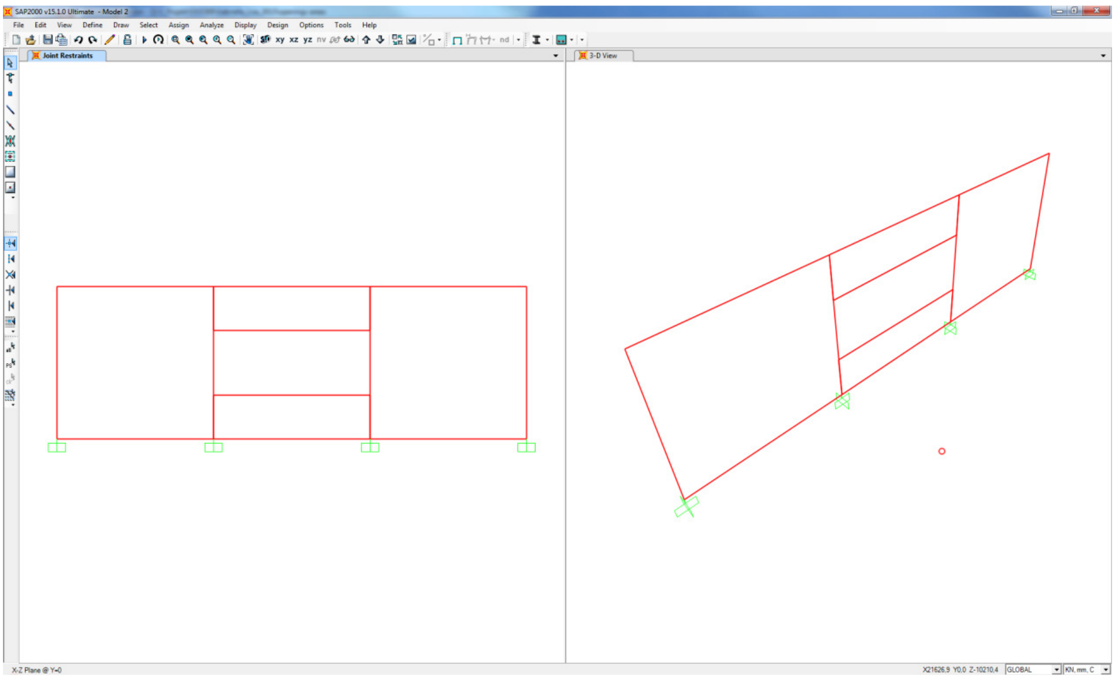
2. An *Analysis & Design model* was created. Analysis lines were created for each panel-part and the elements shared an analysis line.



3. The model was exported to SAP as separated connected elements.

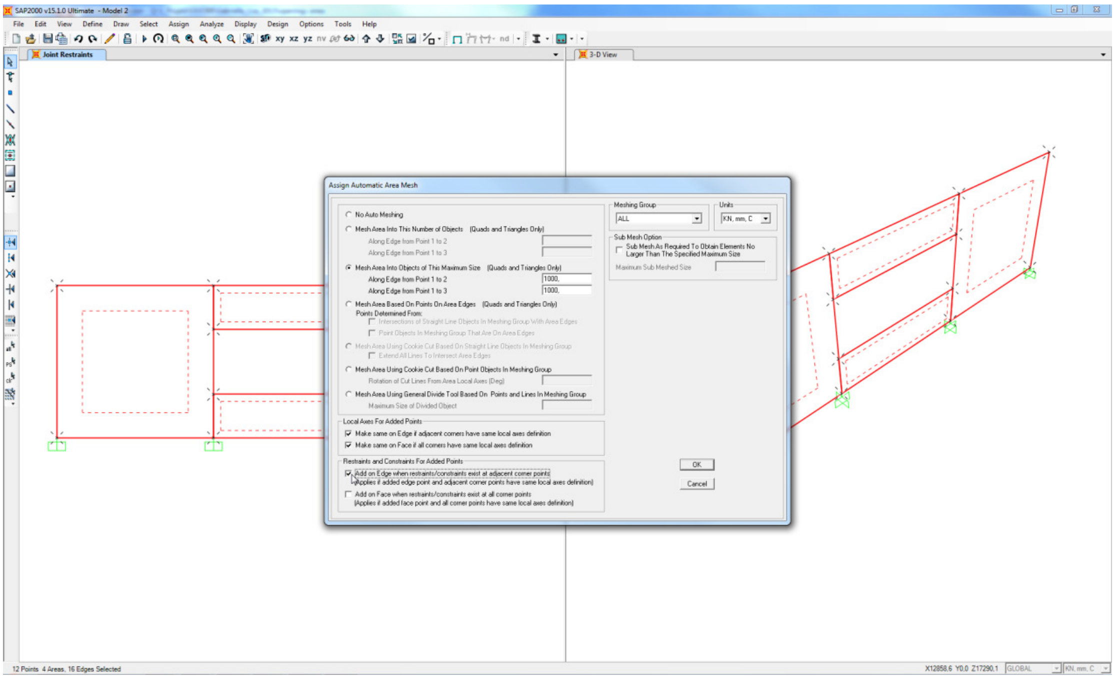


4. The nodes along the bottom edge of the slab were fully restrained.

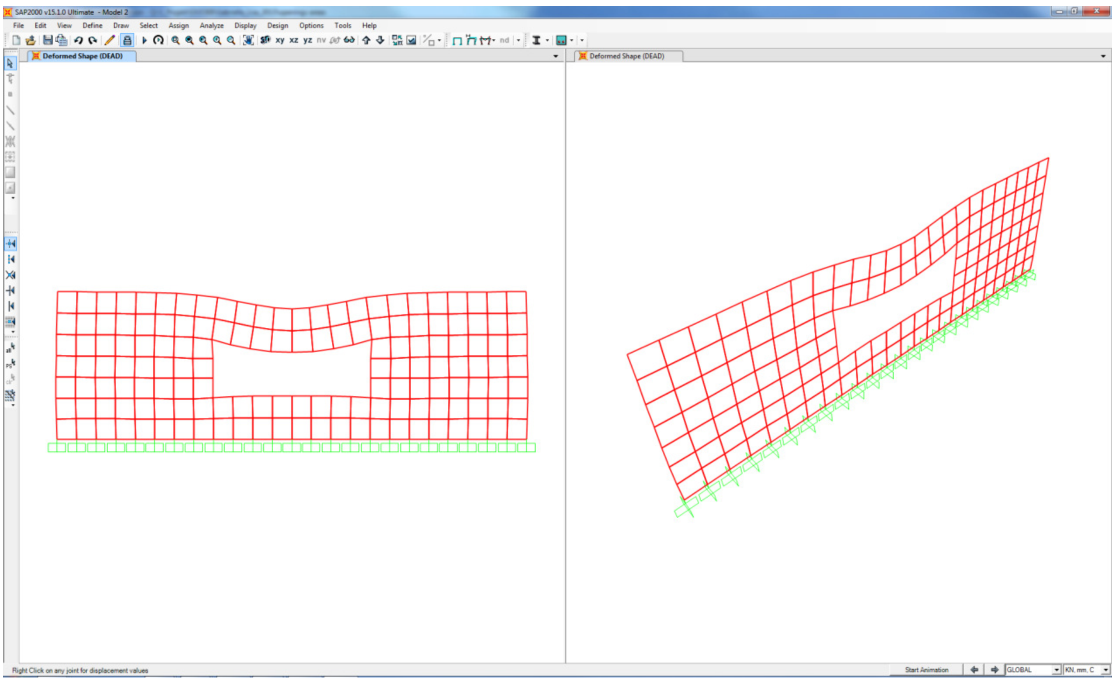


5. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

6. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*



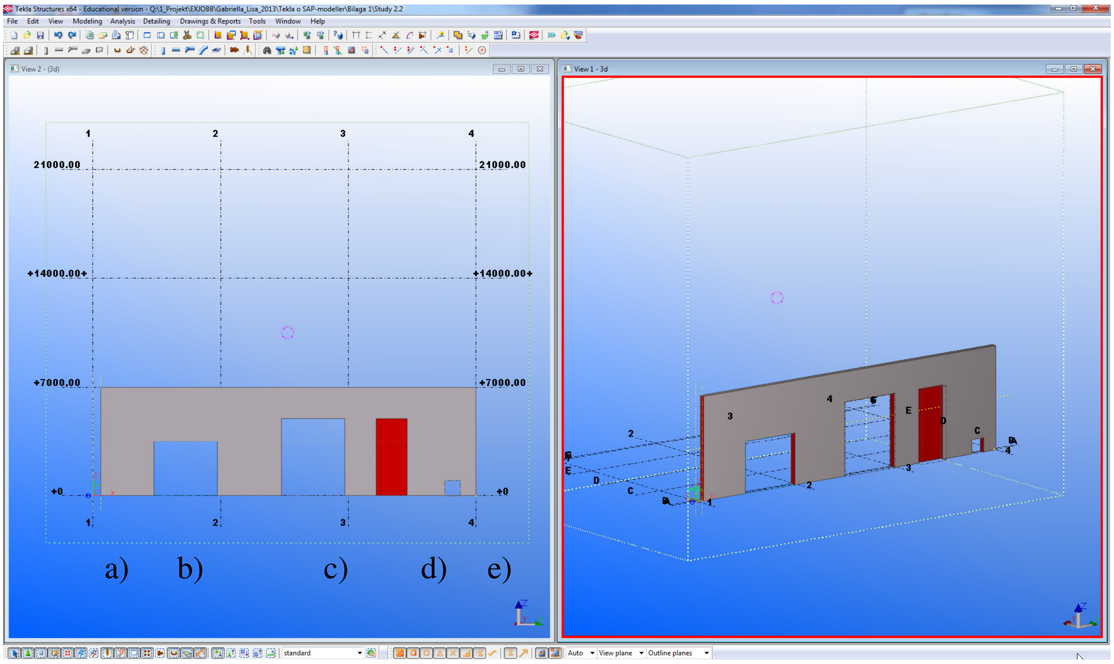
7. An analysis was performed and the created mesh was acceptable. It also was noted that the elements were connected.



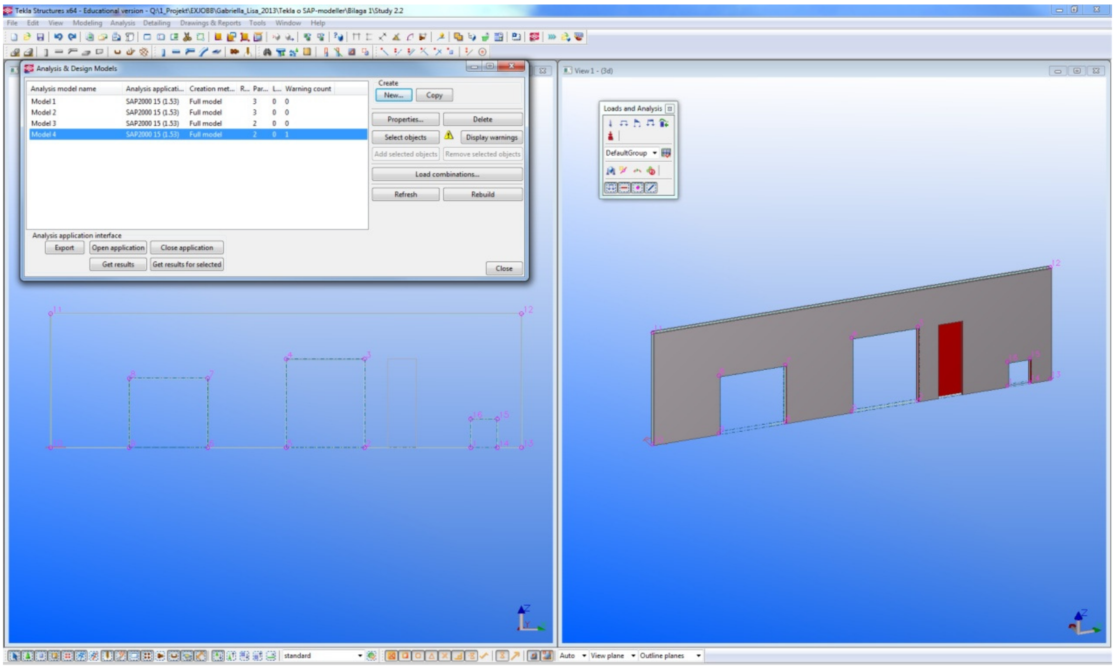
2.3 Export of rectangular openings at the edge of a panel element

1. The model was created using *Concrete panels*-tool and the openings was created using following modelling techniques:

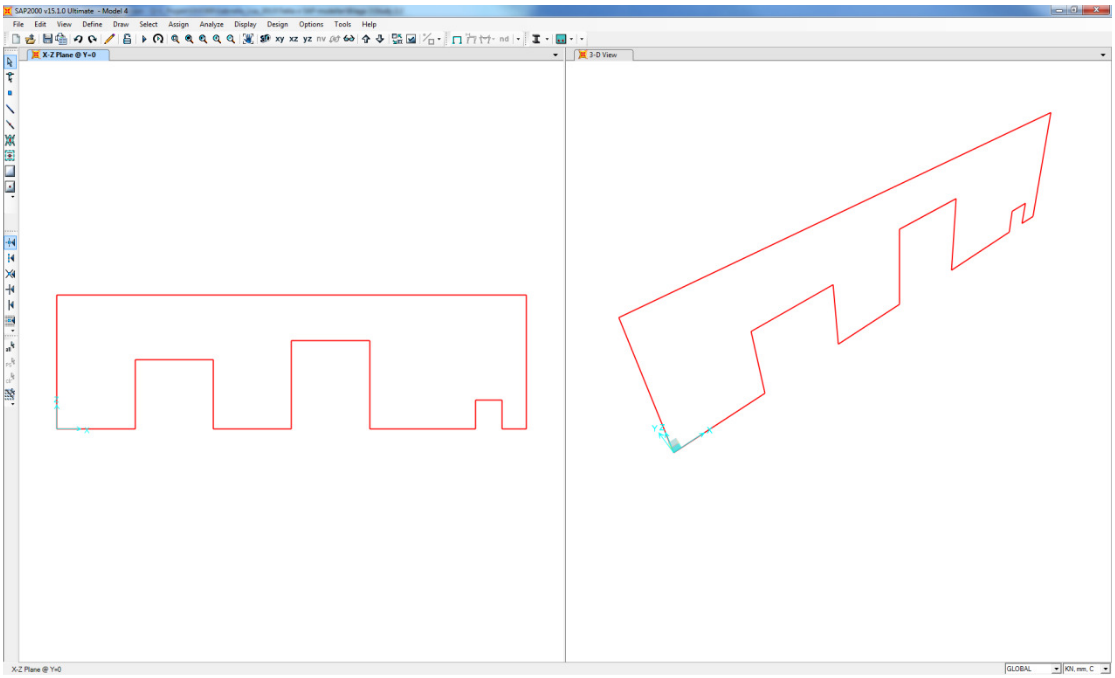
    a. Cut part with line (shortening of the panel)
    b. Cut part with polygon
    c. Cut part with another part
    d. Cut part with another part (a partly cut trough)
    e. Cut part with component (“Hole generation 32”)



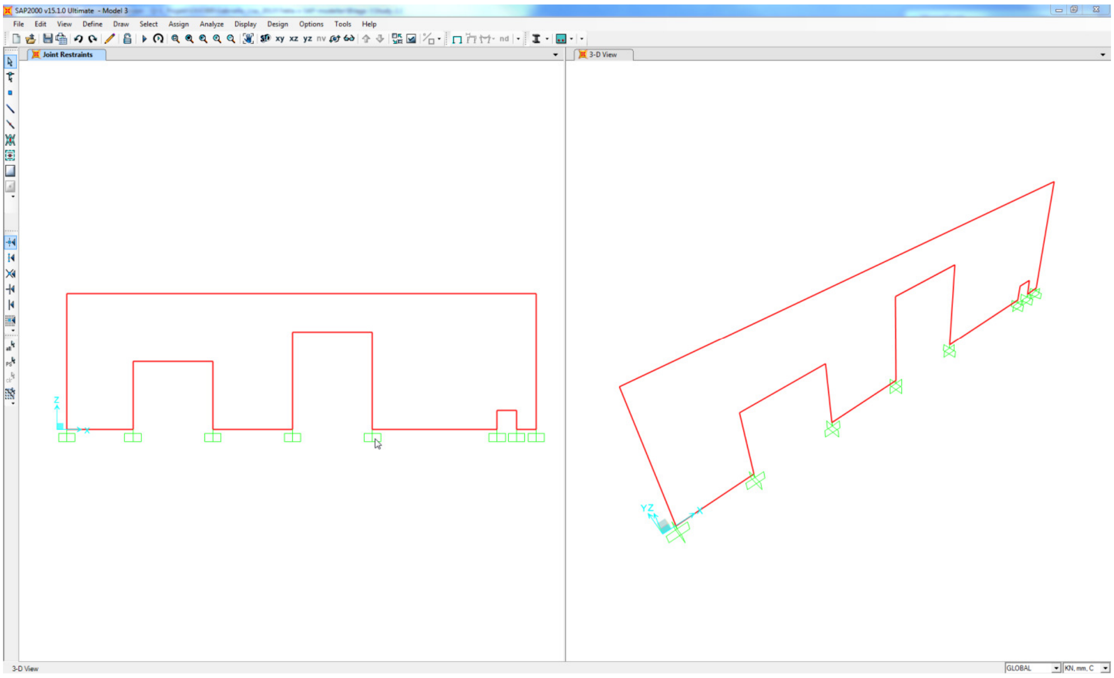
2. An *Analysis & Design model* was created. No analysis lines or nodes was generated for the *partly cut out*.



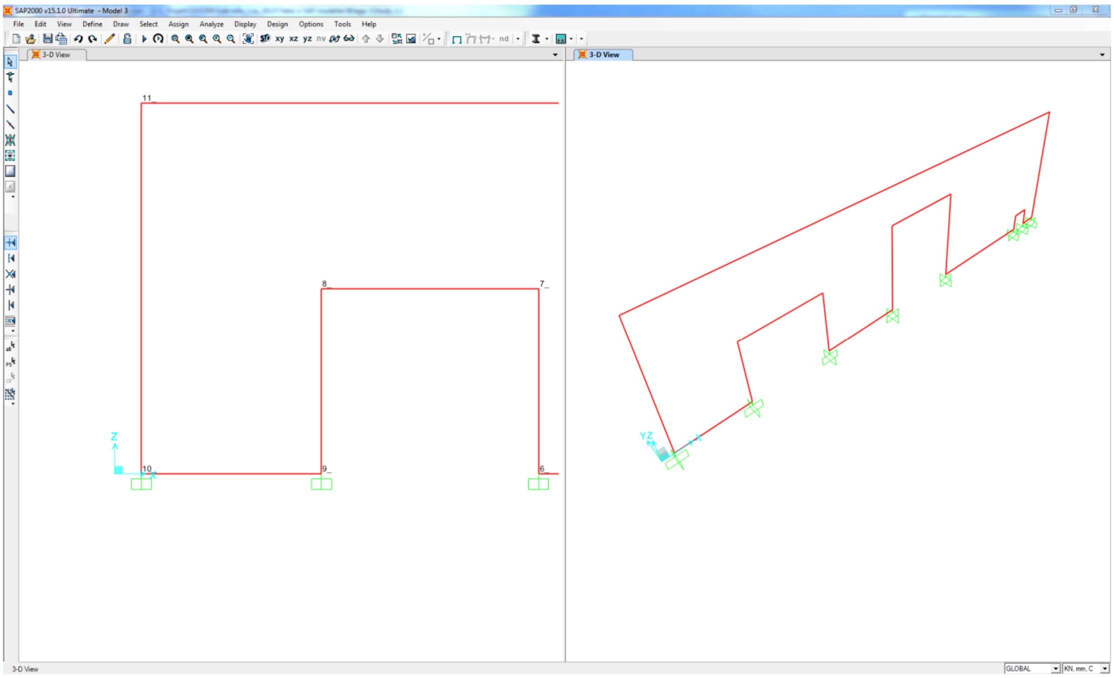
3. The model was exported to SAP. The openings at the edge of the panel were exported correctly independent of used modelling technique.



4. The nodes along the bottom edge of the slab were fully restrained.



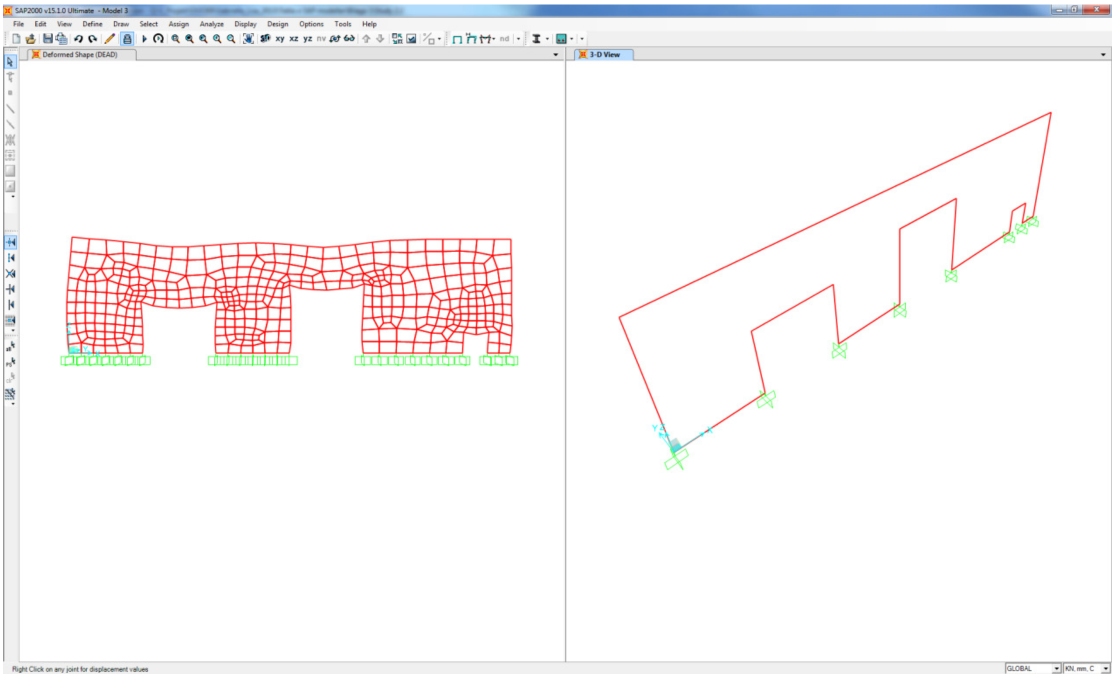
5. The position of origin was not at the corner of the panel; as it used to be, in other words, the shortening of the panel was exported.



6. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Using General Divide Tools Based On Points and Lines In Meshing Group*. The maximum size of divided objects chosen by the program was kept.

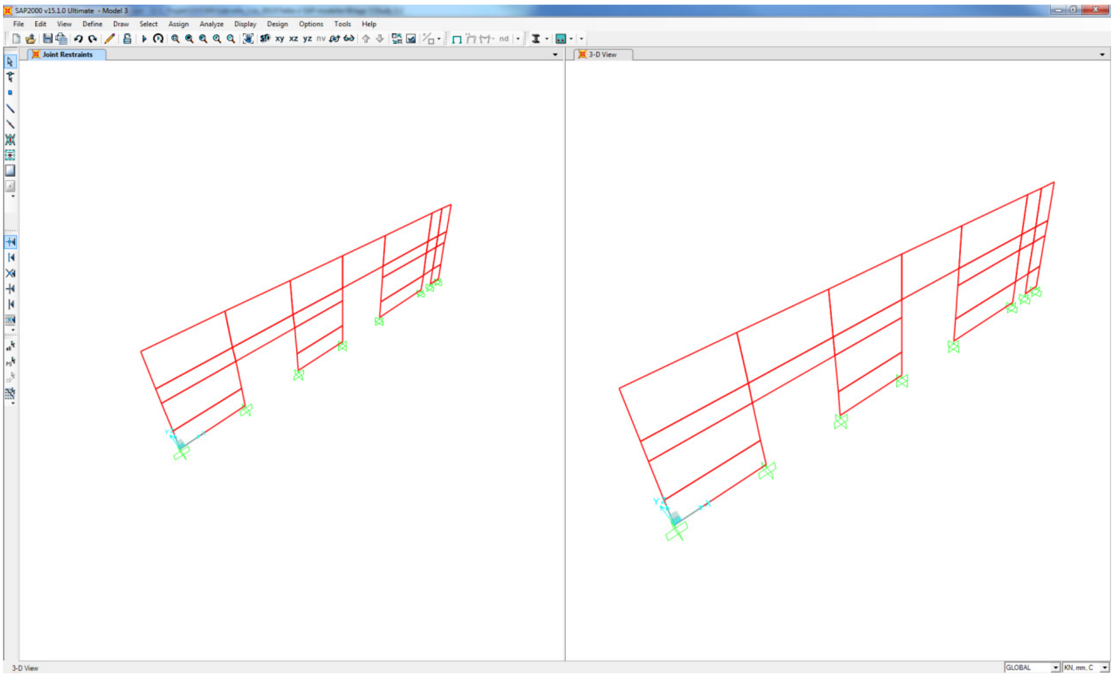
7. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*

8. An analysis of the model was performed and the result of the analysis showed that the program recommended mesh gave an irregular mesh.



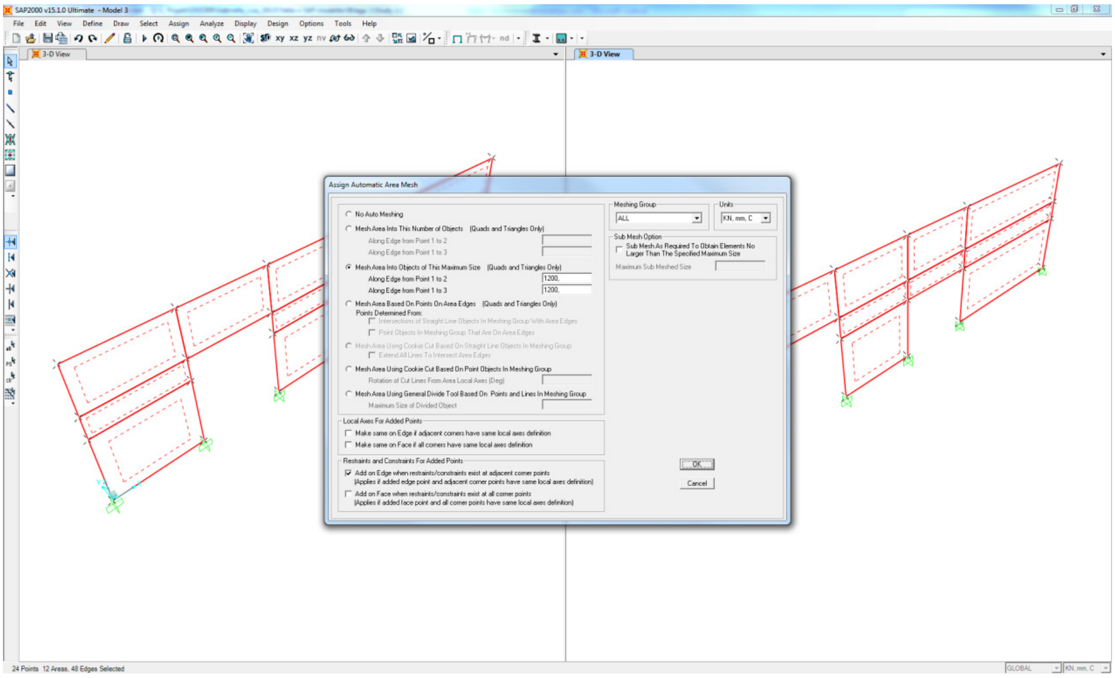
9. The model was unlocked.

10. The model was instead divided into smaller areas in the *Divide Selected Area* box by choosing the option *Divide Area Using Cookie Cut Based On Selected Point Objects with the Rotation of Cut Lines From Area Local Axes.*

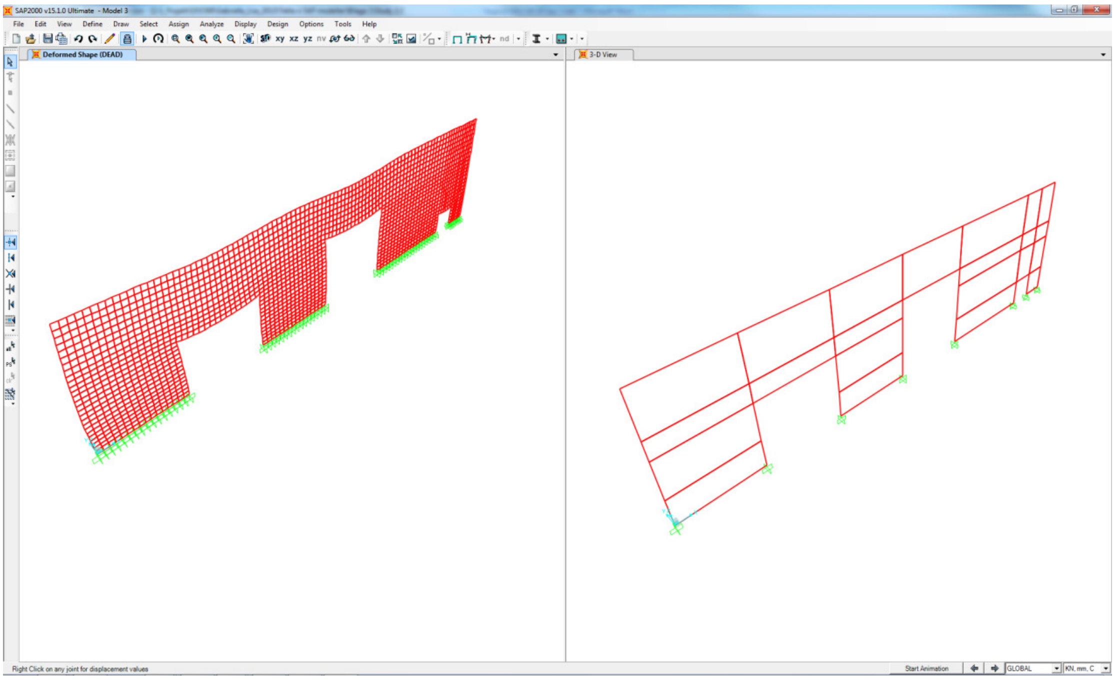


11. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *No Auto Mesh.* The meshing option was changed to *Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

12. *Restrains and Constrains For Added Points* were defined *to Add on Edge when restrains/constrains exist at adjacent corner points.*

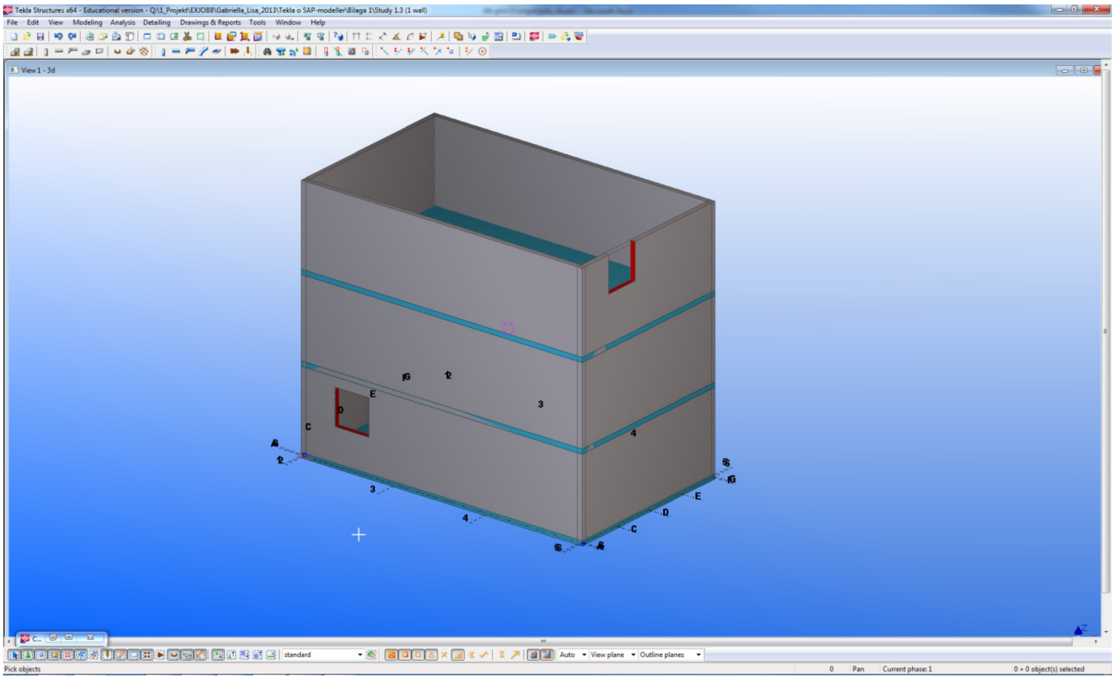


13. A new analysis was performed and the used meshing option gave an accepted mesh.

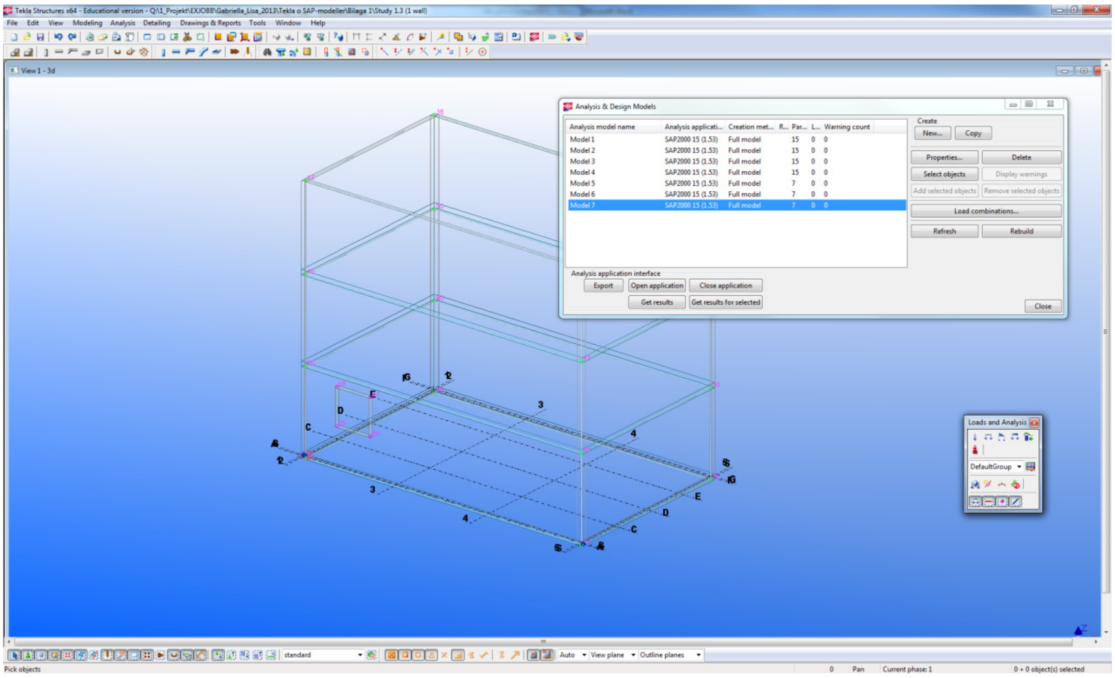


2.4 Export of panel and slab elements with rectangular openings

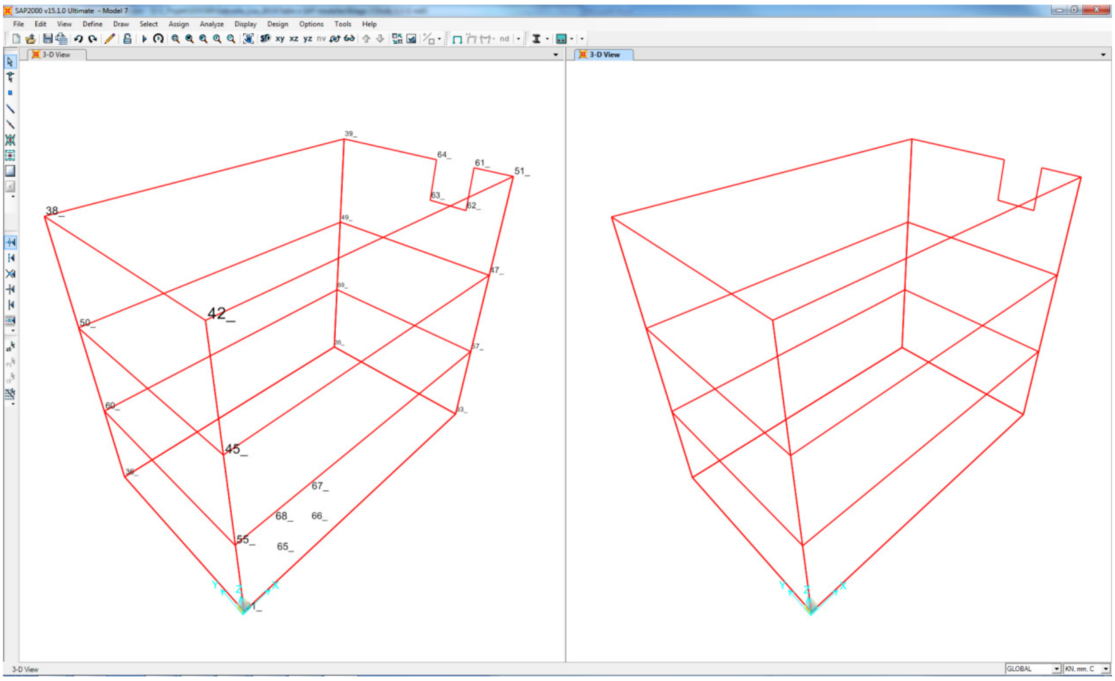
1. The model was created using the *Concrete Panel*- and *Concrete Slab*-tool. Material properties and thicknesses were defined to the elements. The model was created with one panel element along all three floors and one opening was created within one wall and another at the edge of one wall. The openings was created using *Cut part with component* ("Hole generation 32").



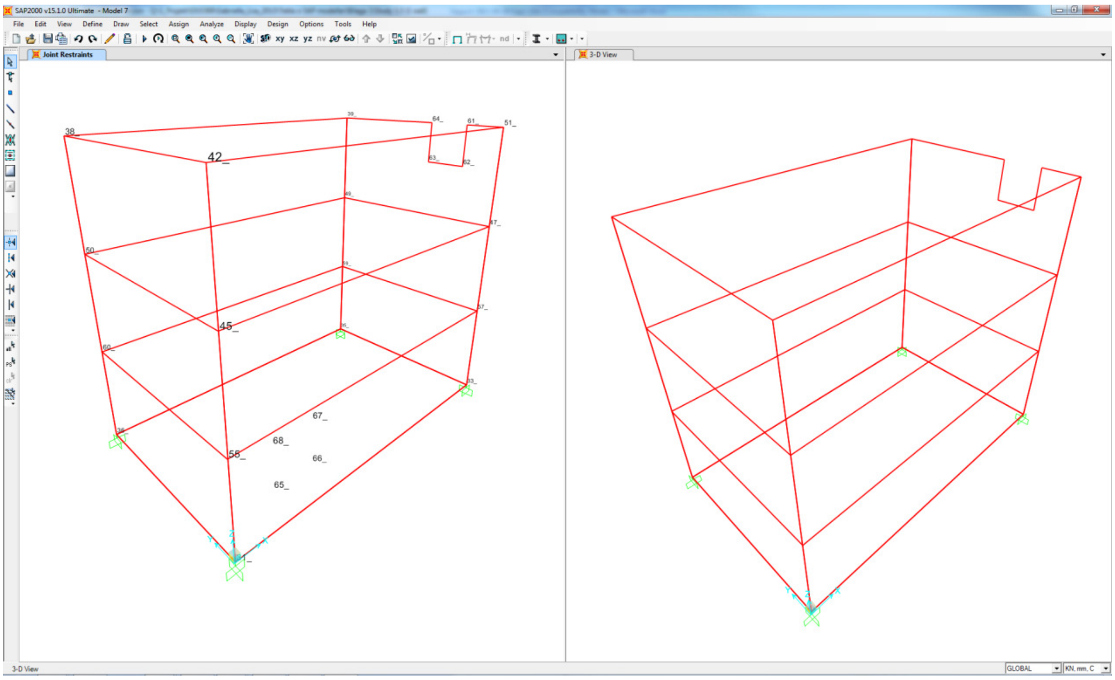
2. An *Analysis & Design model* was created.



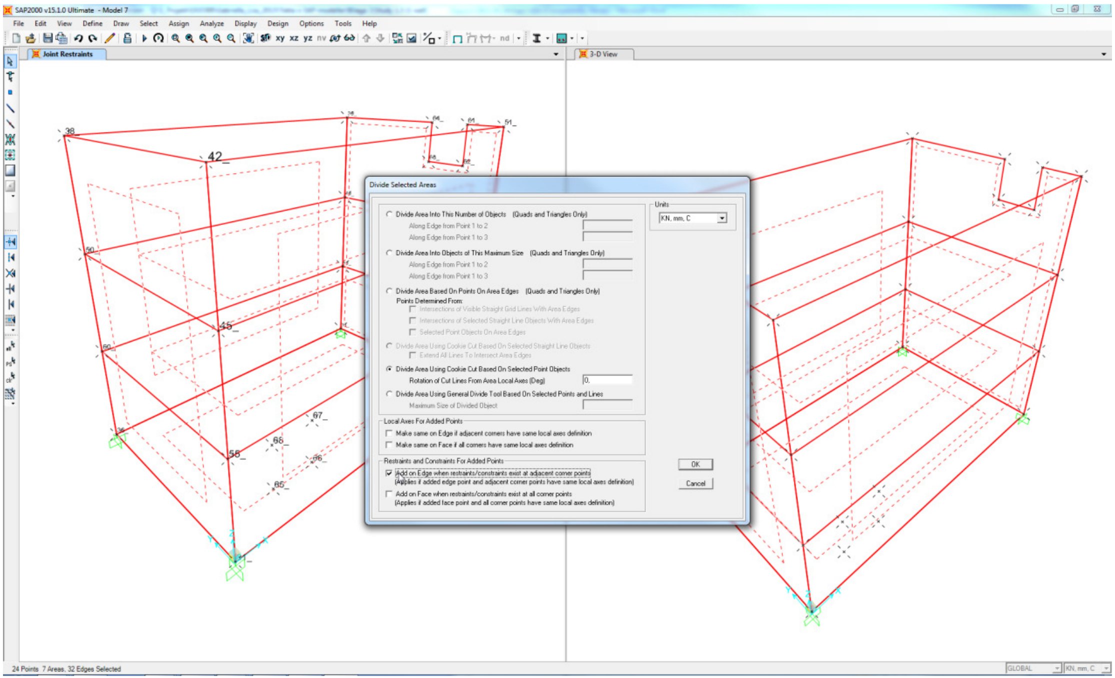
3. The model was exported to SAP and the result showed that the opening at the edge of the panel was exported while the opening within the panel was not exported, however the nodes of the opening were exported.



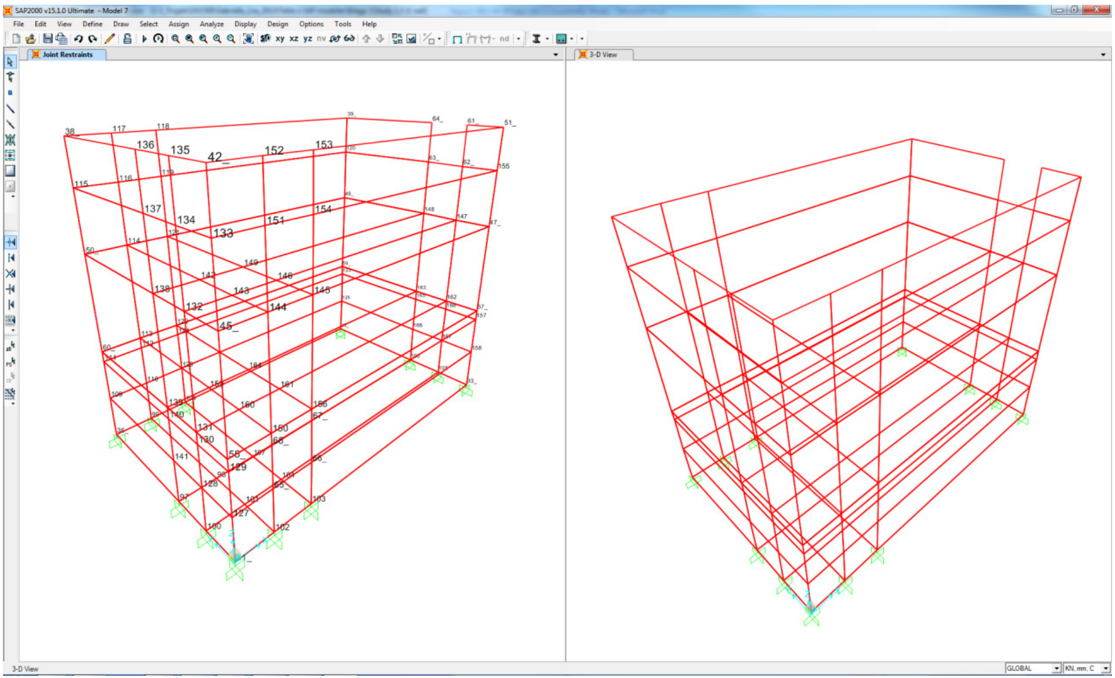
4. Restraints were assigned to the edge nodes.



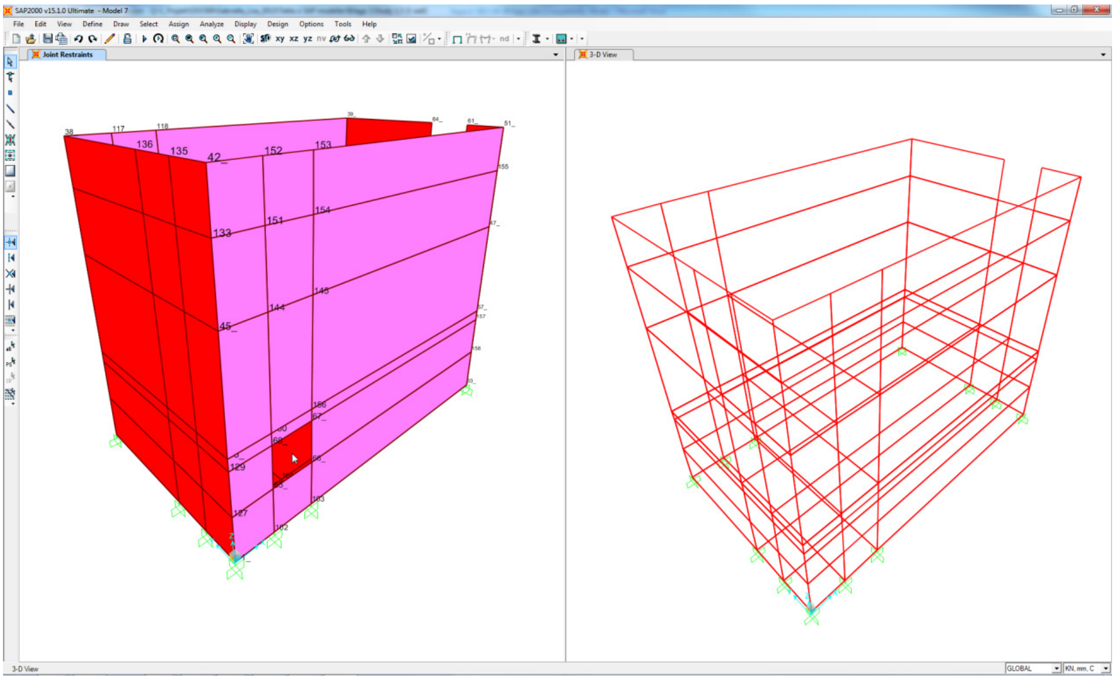
5. The model was divided into smaller areas in the *Divide Selected Area* box by choosing the option *Divide Area Using Cookie Cut Based On Selected Point Objects with the Rotation of Cut Lines From Area Local Axes.*



6. The model was divided into smaller areas.

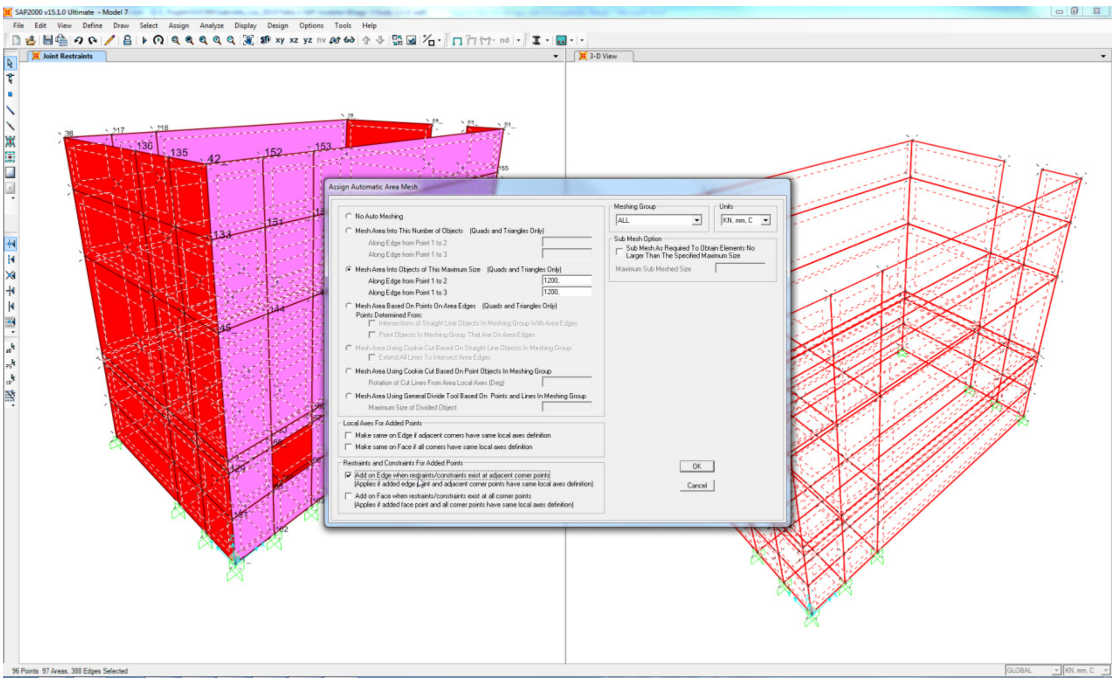


7. The area of the opening was deleted based on the node numbering.

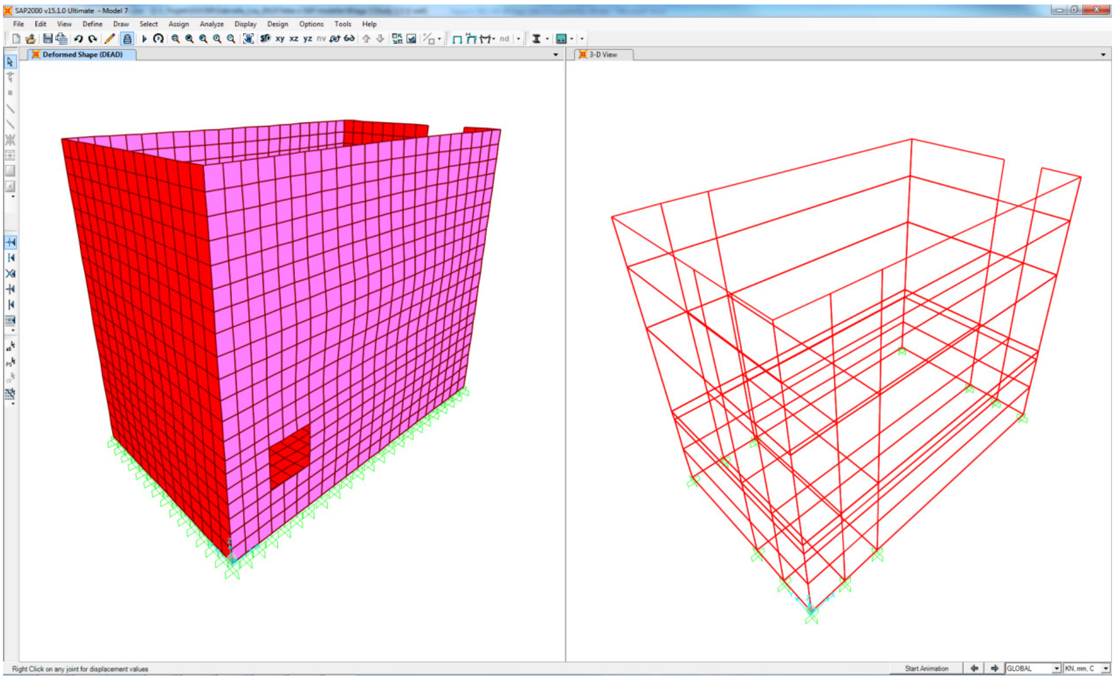


8. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *No Auto Mesh.* The meshing option was changed to *Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

9. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*

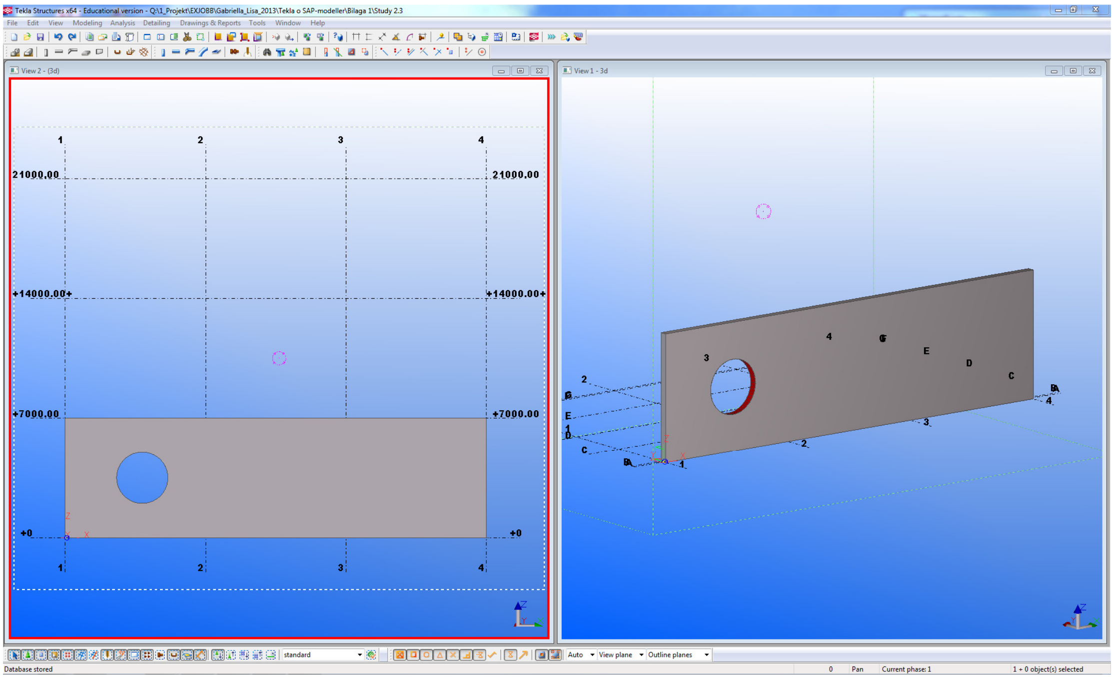


10. An analysis was performed and the result showed an acceptable mesh.

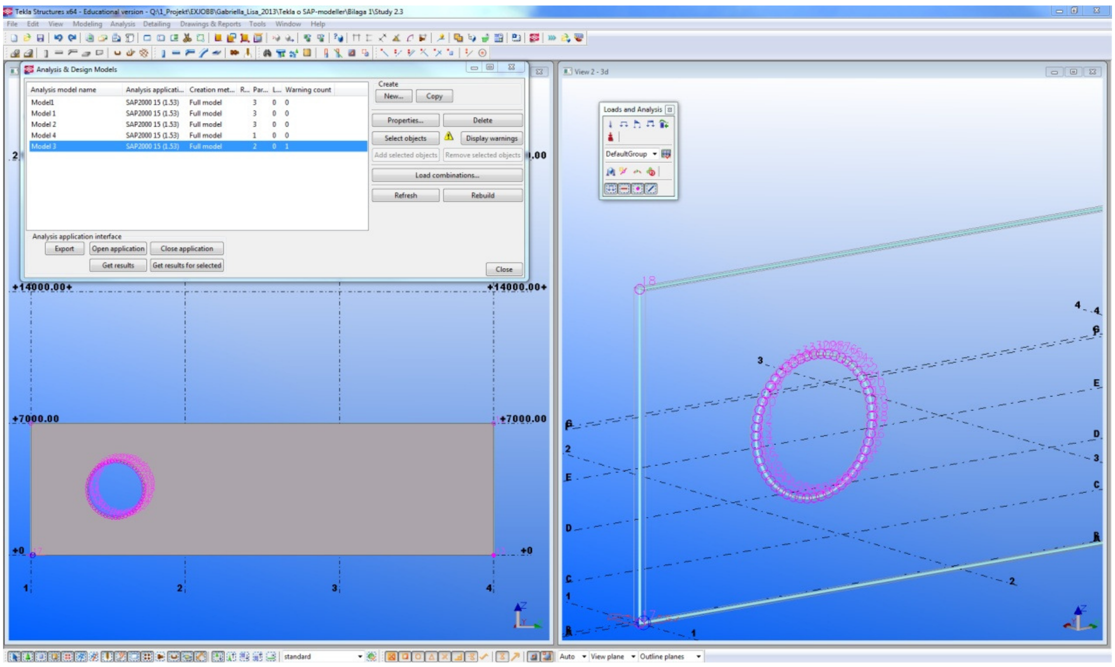


2.5 Export of a circular opening within a panel element

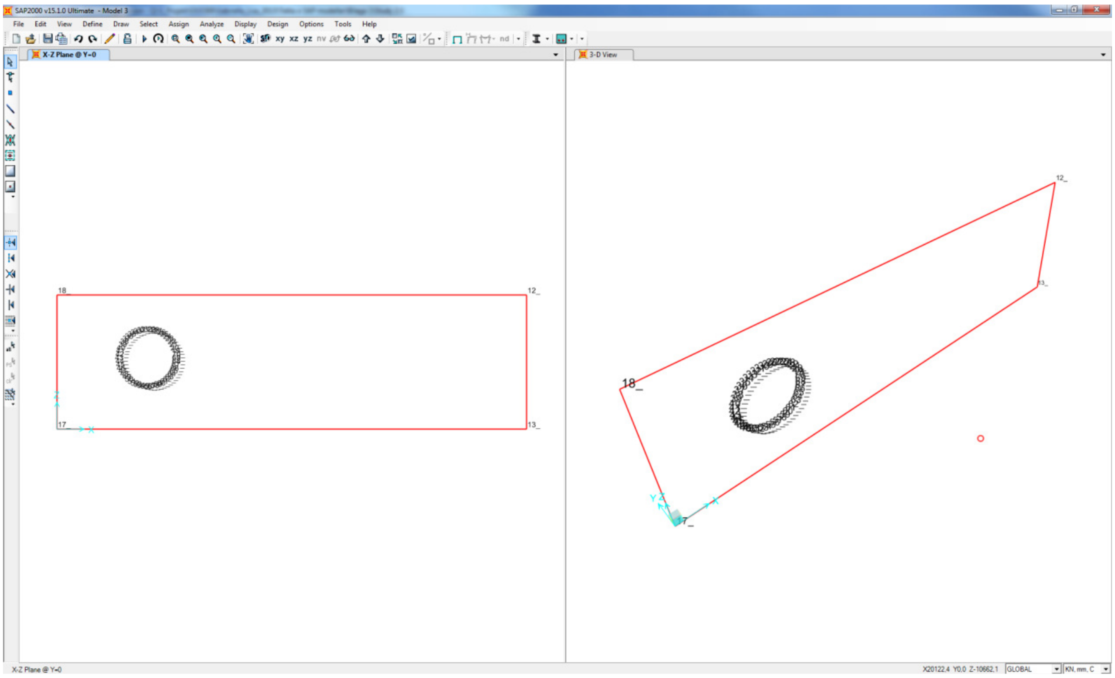
1. A concrete panel was modelled with *concrete panel*-tool and a circular opening created using the modelling technique "Hole generation".



2. An *Analysis & Design model* was created. Analysis lines were created for both the panel and the circular opening.

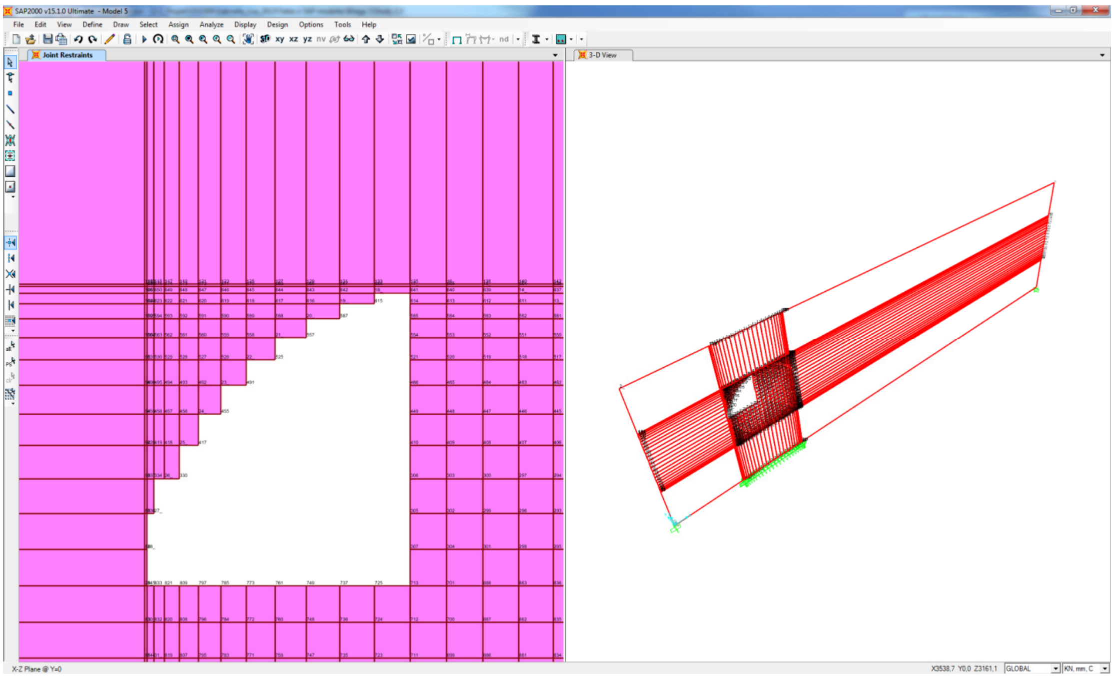


3. The model was exported. The panel together with nodes of the opening was exported, but not the opening itself.



4. The model was divided into smaller areas in the *Divide Selected Area* box by choosing the option *Divide Area Using Cookie Cut Based On Selected Point Objects with the Rotation of Cut Lines From Area Local Axes.*

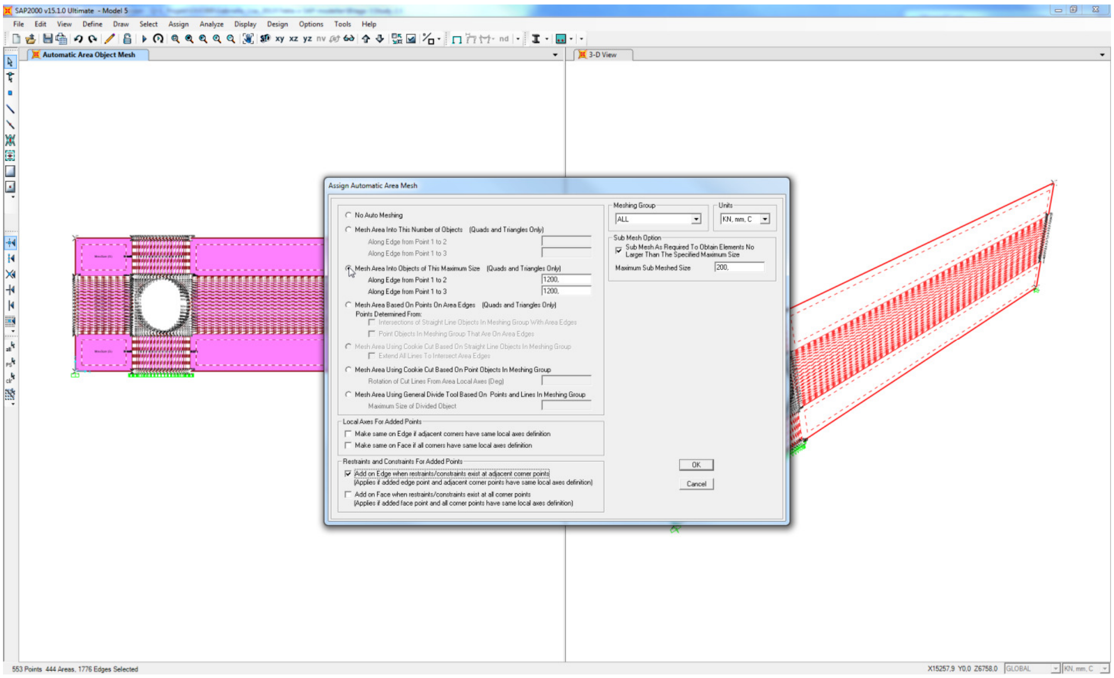
5. The opening was created by deleting all area elements in between the nodes defining the opening.



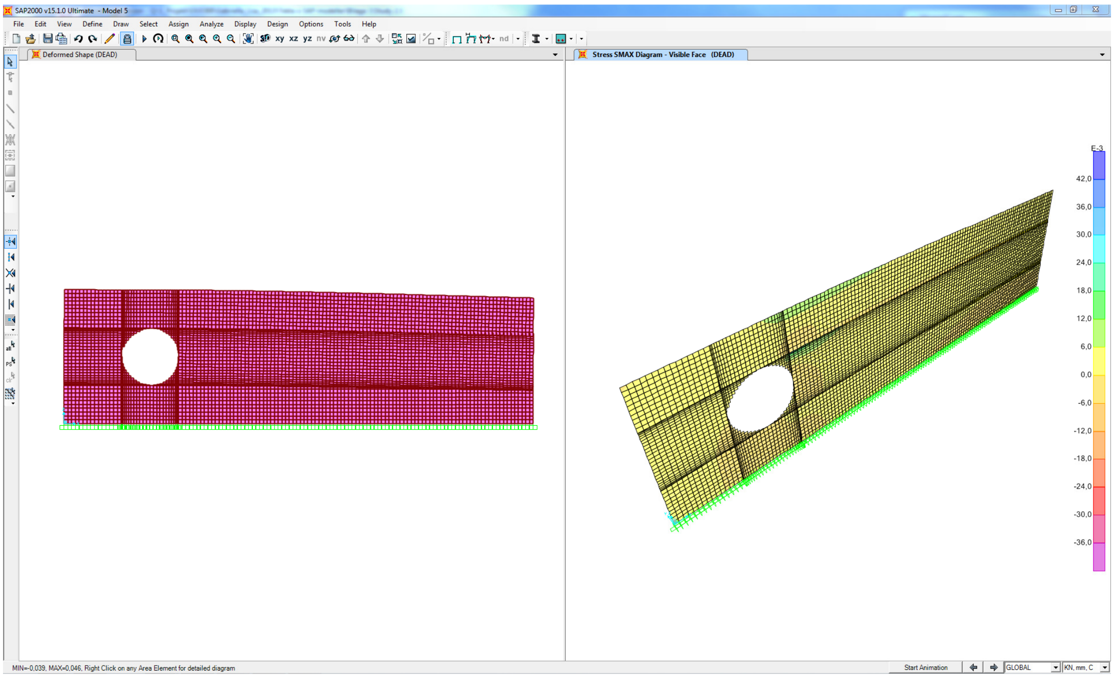
6. The bottom corner nodes of the panel were fully restrained.

7. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *No Auto Mesh.* The meshing option was changed to *Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept. In order to get a sufficient fine mesh the option *Sub Mesh As Required To Obtain Elements No Larger Than The Specified Maximum Size* were used and a maximum size of the elements were specified.

8. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*

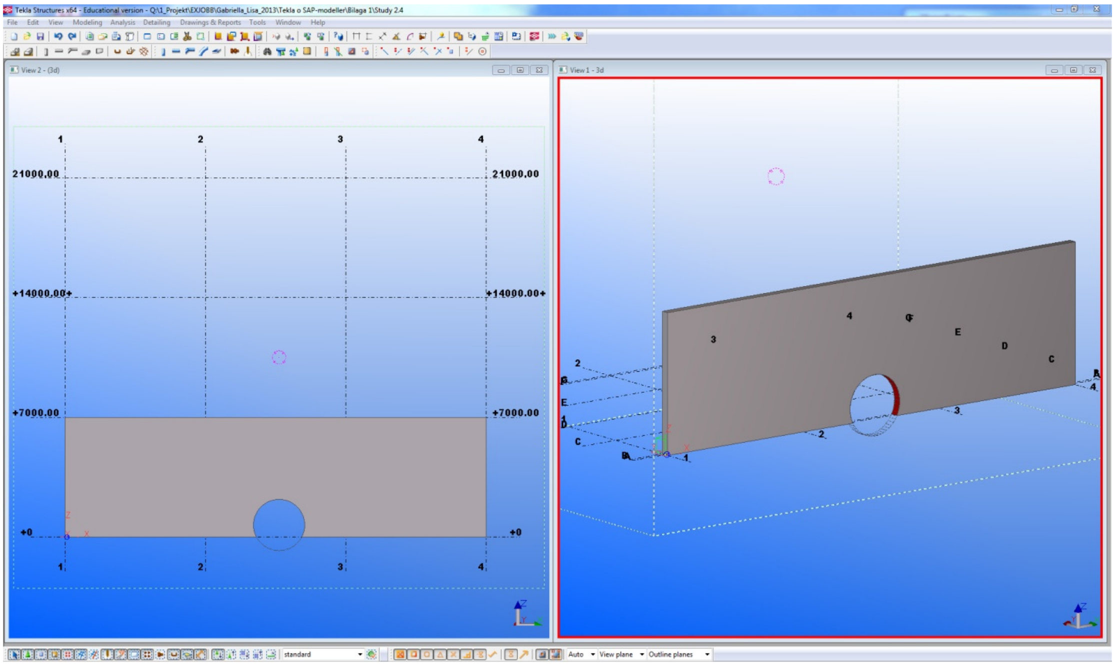


9. An analysis was performed and it resulted in unaccepted mesh.

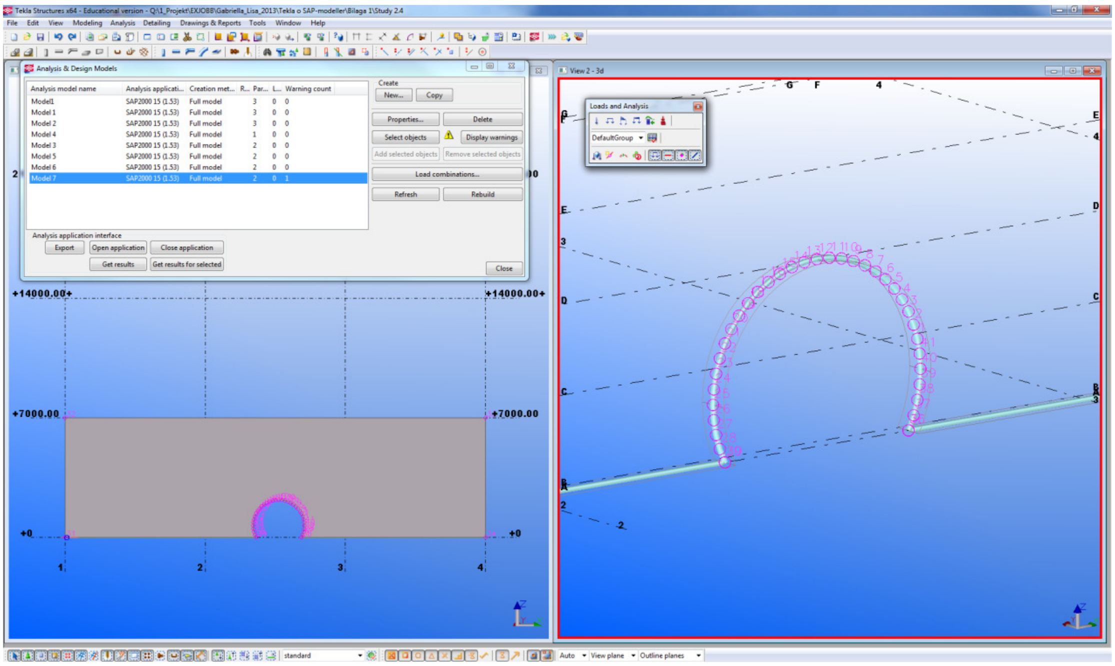


2.6 Export of a circular opening at the edge of a panel element

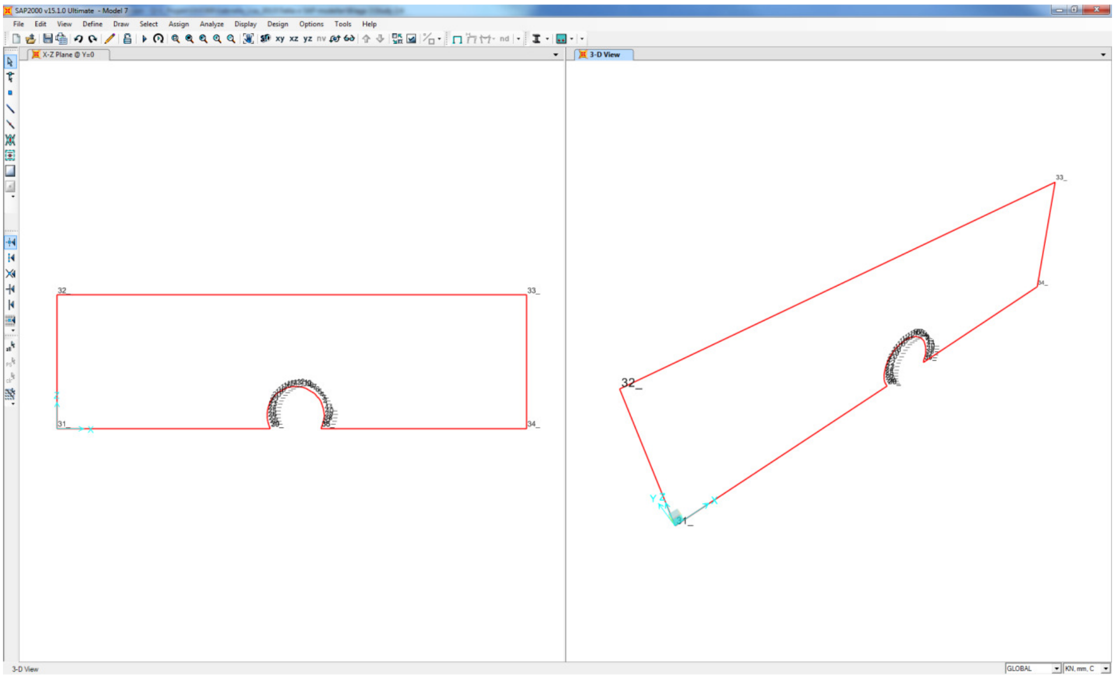
1. A concrete panel containing a circular opening at the edge was modelled by the "Hole generation".



2. The *Analysis & Design model* was created. Analysis lines and nodes were generated for both the panel and the circular opening.



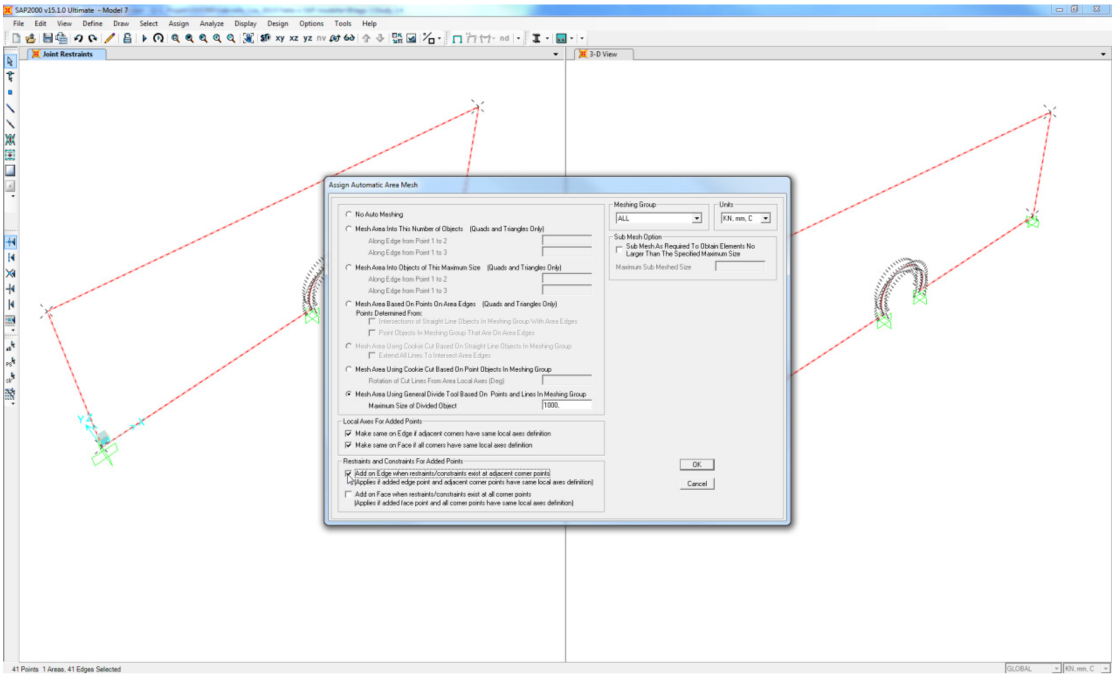
3. The model was exported to SAP. Both the panel and the circular opening were exported.



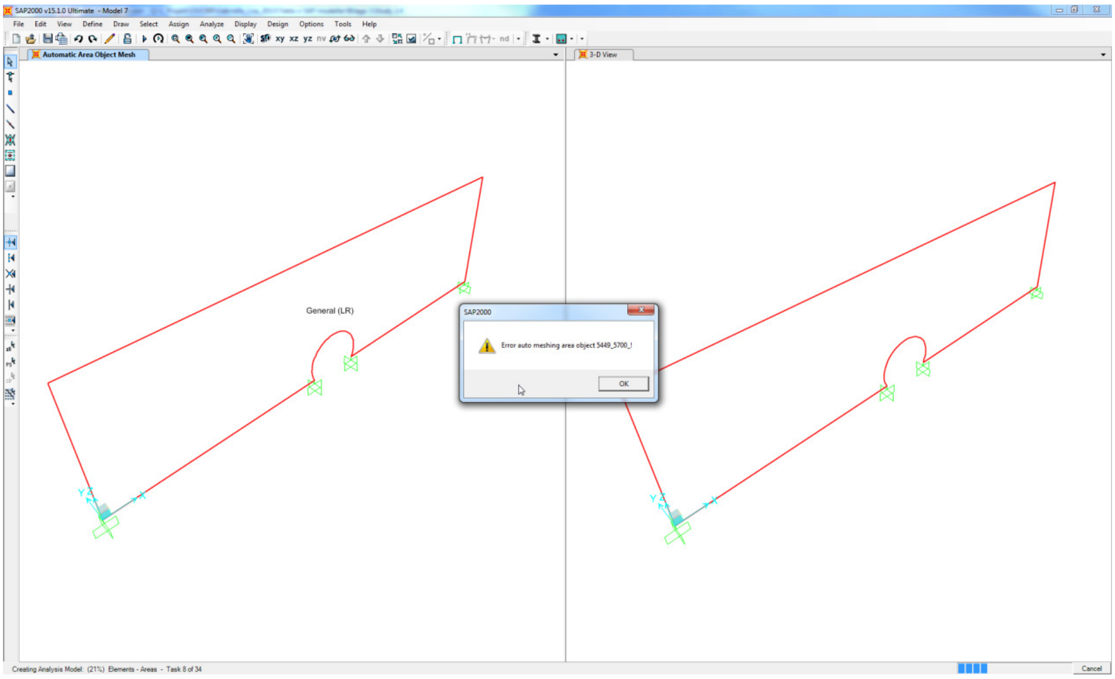
4. The nodes along the bottom edge of the panel were fully restrained.

5. By opening the *Assign Automatic Area Mesh* box it could be seen that the program chooses/recommend the meshing option *Mesh Area Using General Divide Tools Based On Points and Lines In Meshing Group*. The maximum size of divided objects chosen by the program was kept.

6. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*



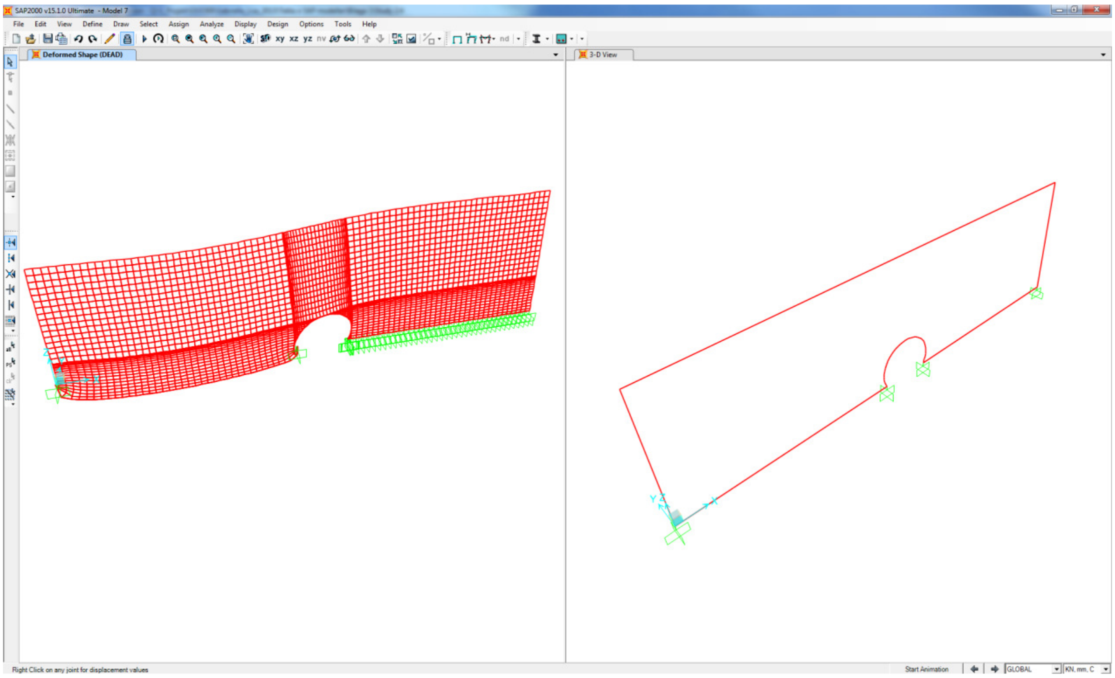
7. An analysis was performed but it was stopped by an error message. This may be caused by the too closely spaced nodes in the opening.



8. The meshing choice was changed to *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only)*. The maximum size chosen by the program was kept. In order to get a sufficient fine mesh the option *Sub Mesh As Required To Obtain Elements No Larger Than The Specified Maximum Size* was used and a maximum size of the elements were specified.

9. *Restrains and Constrains For Added Points* were defined to *Add on Edge when restrains/constrains exist at adjacent corner points*.

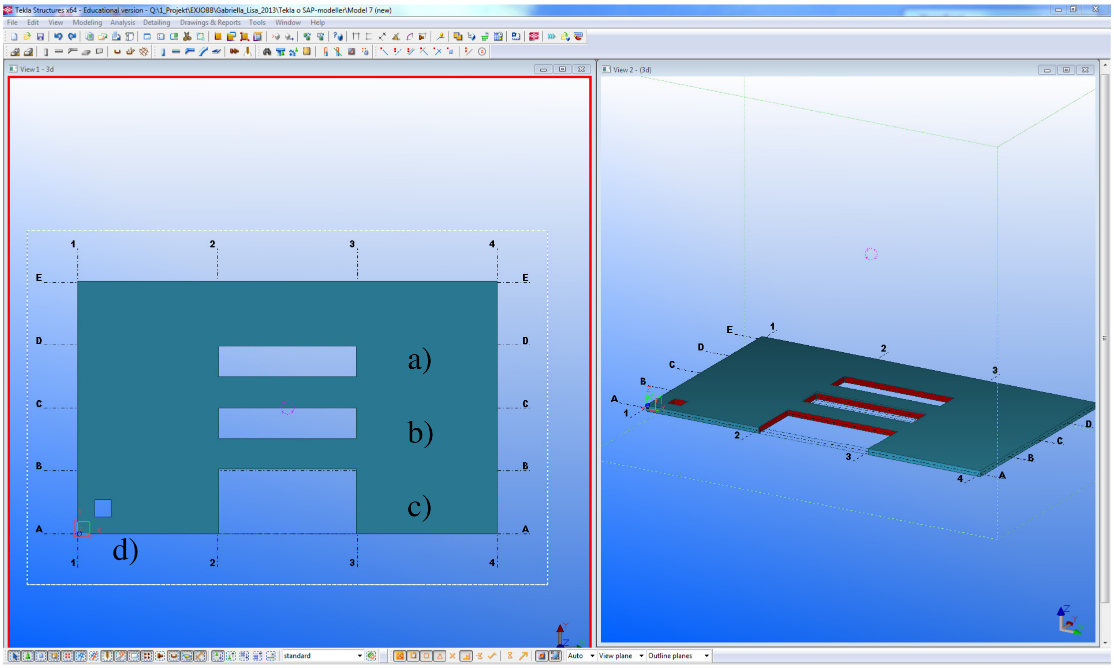
10. An analysis was performed and the result clearly indicates that the mesh option not was acceptable.



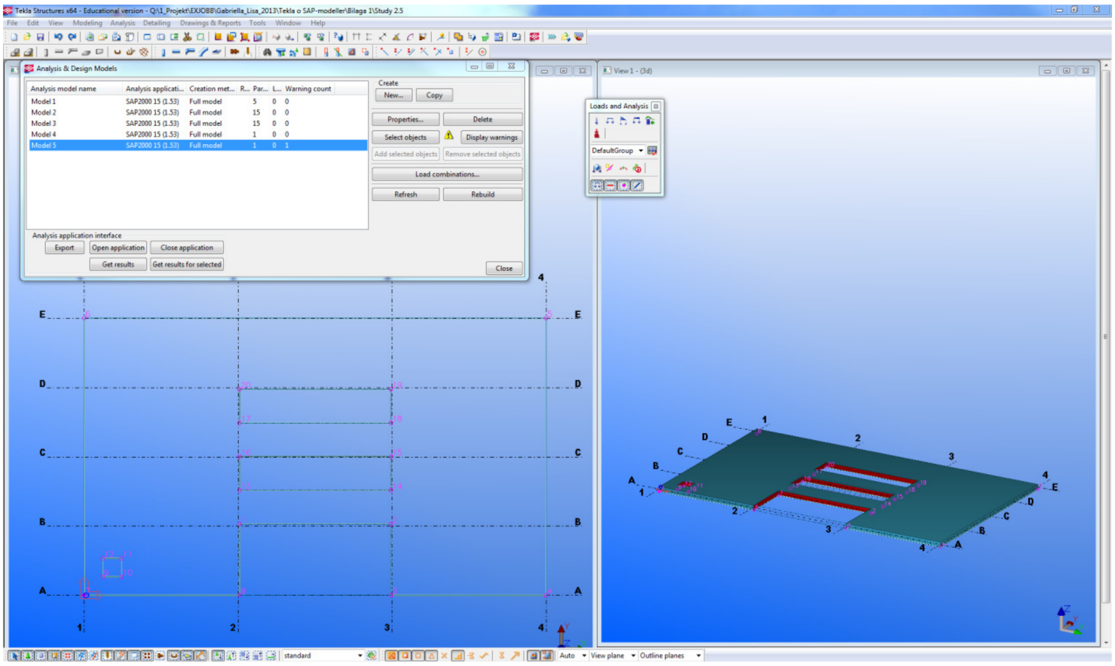
2.7 Export of rectangular openings in a slab element

1. The slab was modelled in Tekla the *concrete slab*-tool and the openings were modelled using the following modelling techniques:

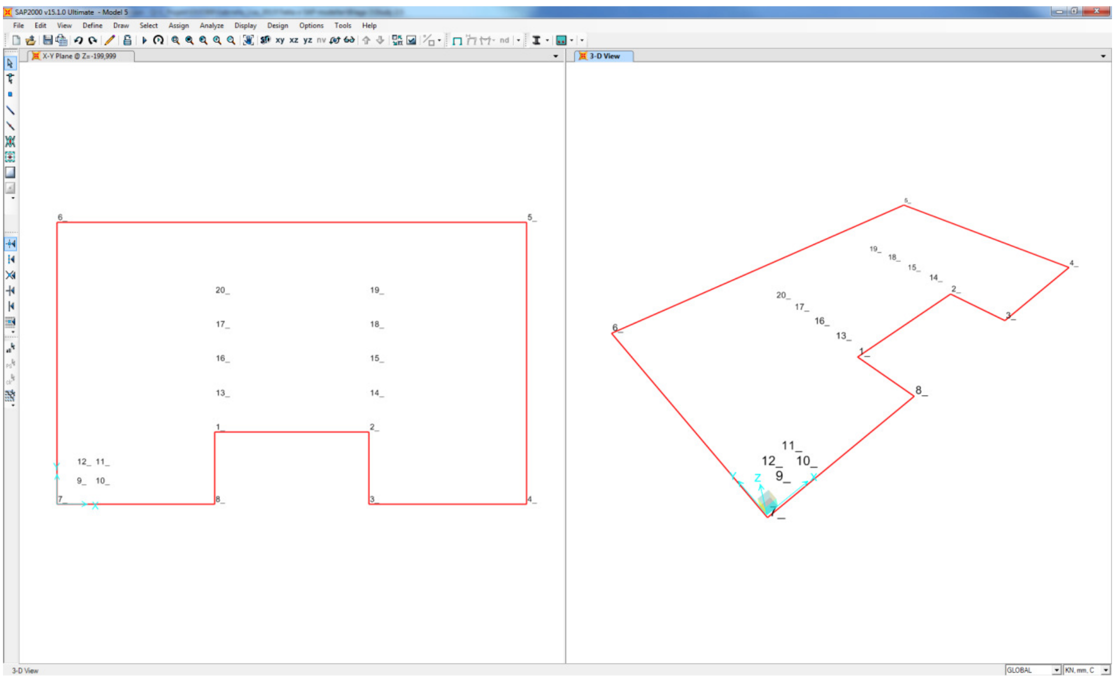
    a. Cut part with polygon
    b. Cut part with another part
    c. Cut part with another part – no opening but party cut through
    d. Cut part with component (“Hole generation 32”)



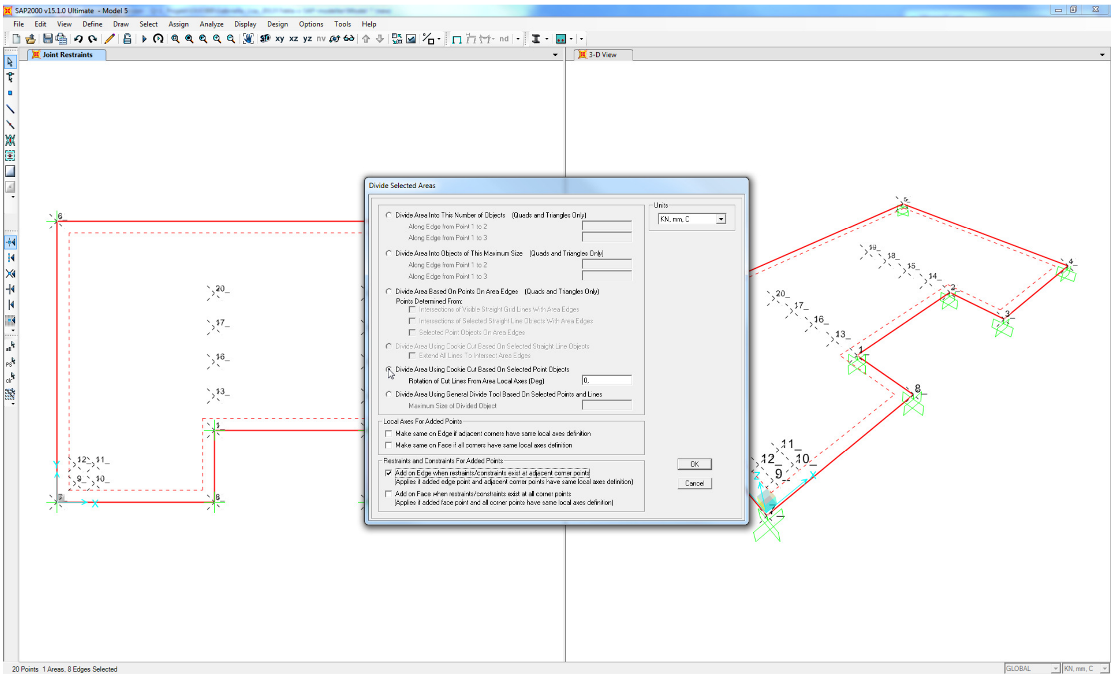
2. The *Analysis & Design model* was created. Analysis lines with nodes were generated for both the slab and each opening.



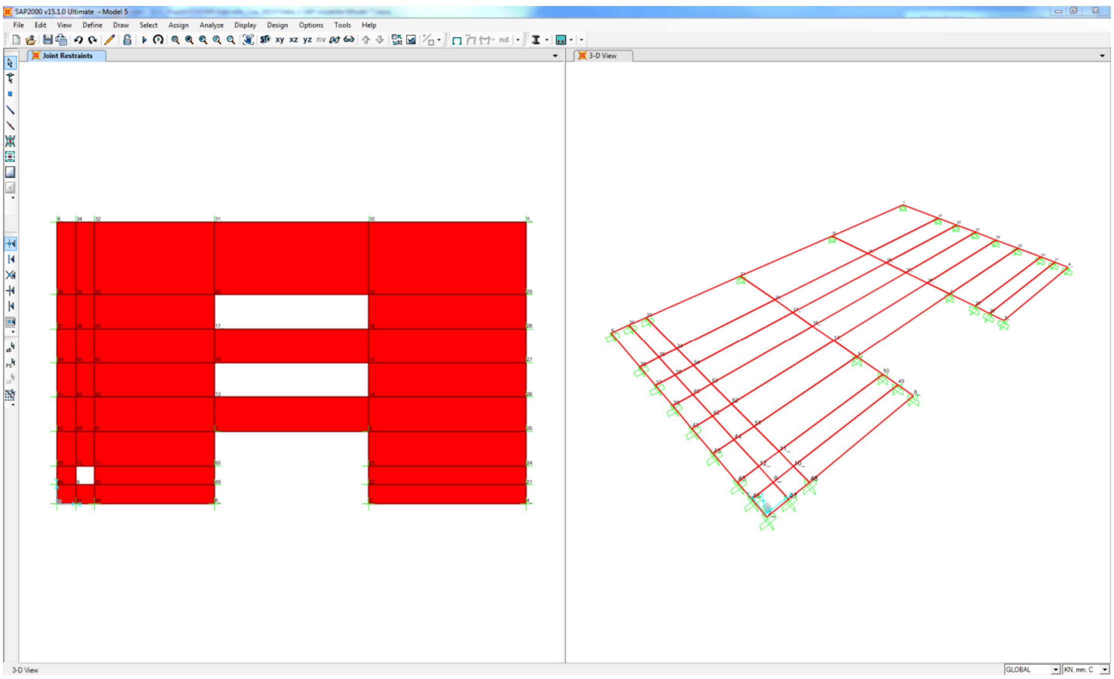
3. The *Export*-link was used. The result of the export was similar to the one concerning a panel containing openings. The opening at the edge of the slab were exported while the openings within the slab not were transferred. For the openings in the slab only the nodes were exported.



4. The model was divided into smaller areas in the *Divide Selected Area* box by choosing the option *Divide Area Using Cookie Cut Based On Selected Point Objects with the Rotation of Cut Lines From Area Local Axes.*

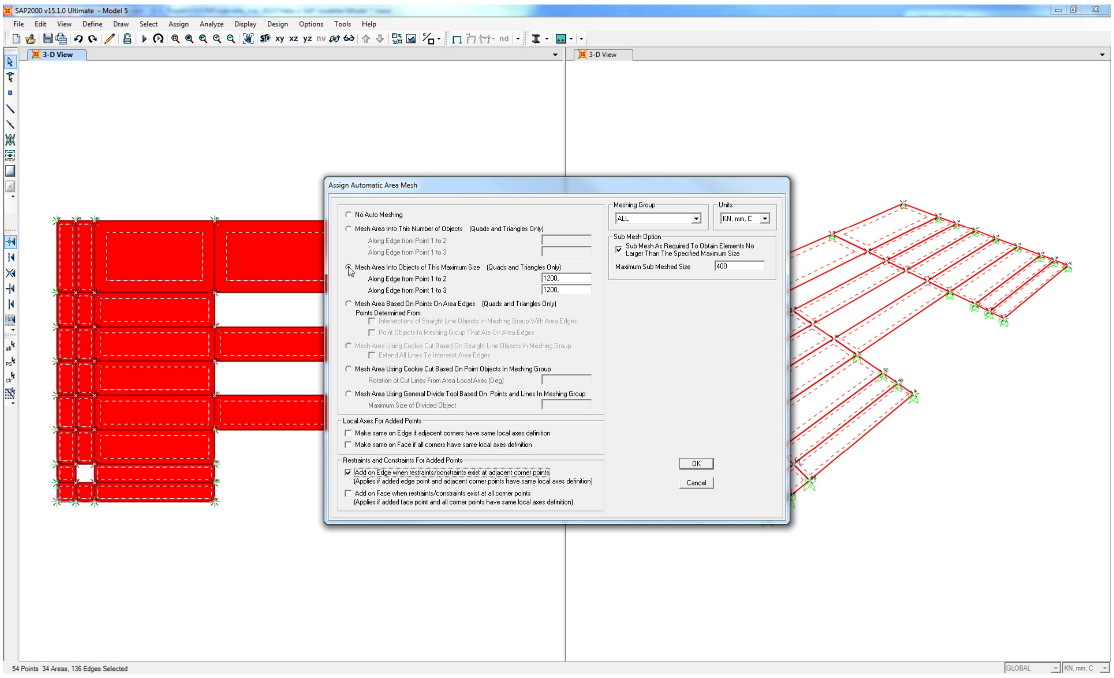


5. The areas in between the nodes of the openings were deleted.
6. The nodes on the outer edge of the slab were fully restrained.

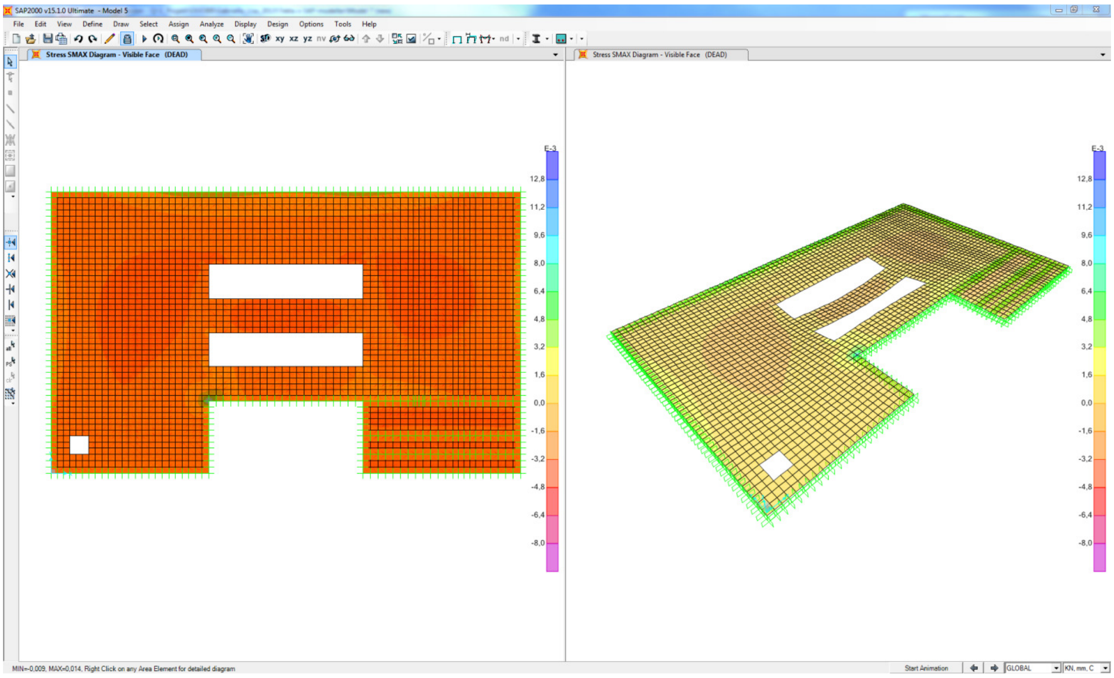


7. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *No Auto Mesh.* The meshing option was changed to *Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept. In order to get a sufficient fine mesh the option *Sub Mesh As Required To Obtain Elements No Larger Than The Specified Maximum Size* was used and a maximum size of the elements was specified.

8. *Restrains and Constrains for Added Points* were defined to *Add on Edge when restrains/constrains exist at adjacent corner points*.



9. An analysis was performed and an acceptable mesh was generated.

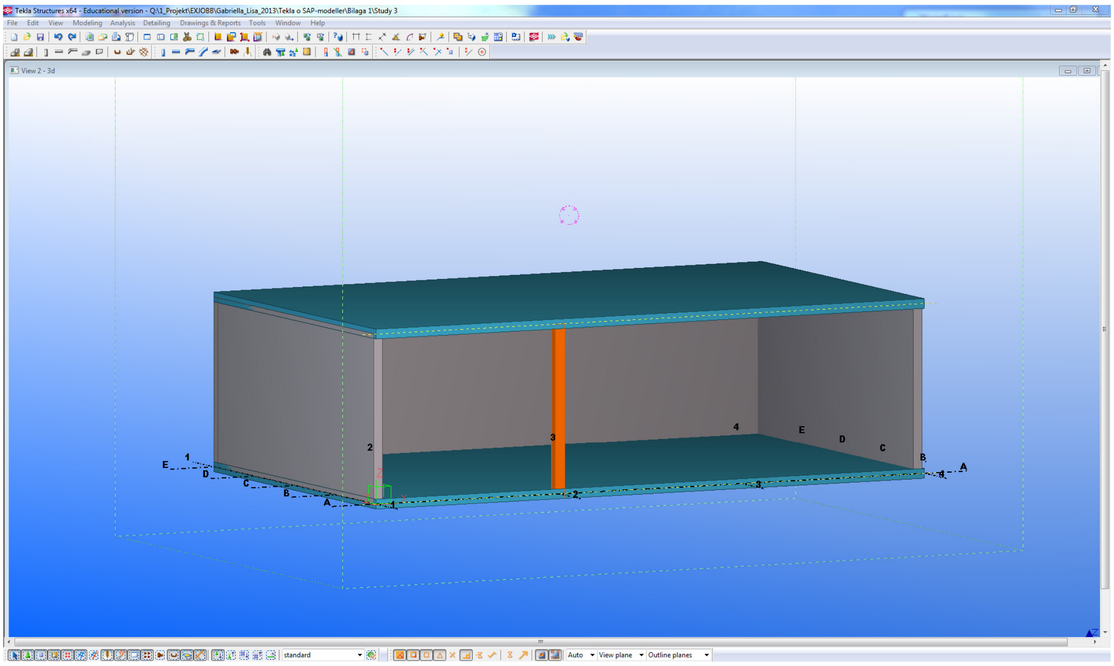


3 Export of connected panel, slab beam and column elements

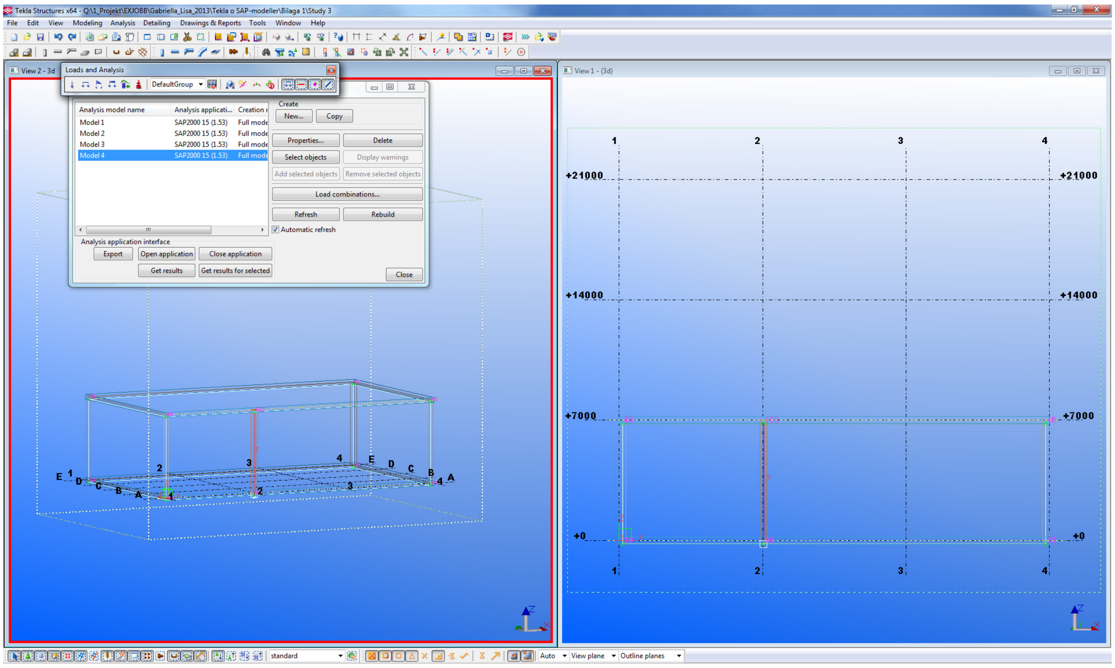
The purpose of this study was to identify feasibilities and limitations of the export from TS to SAP of panel and slab elements modelled in connection to beam and column elements.

3.1 Export of connected slabs and column elements

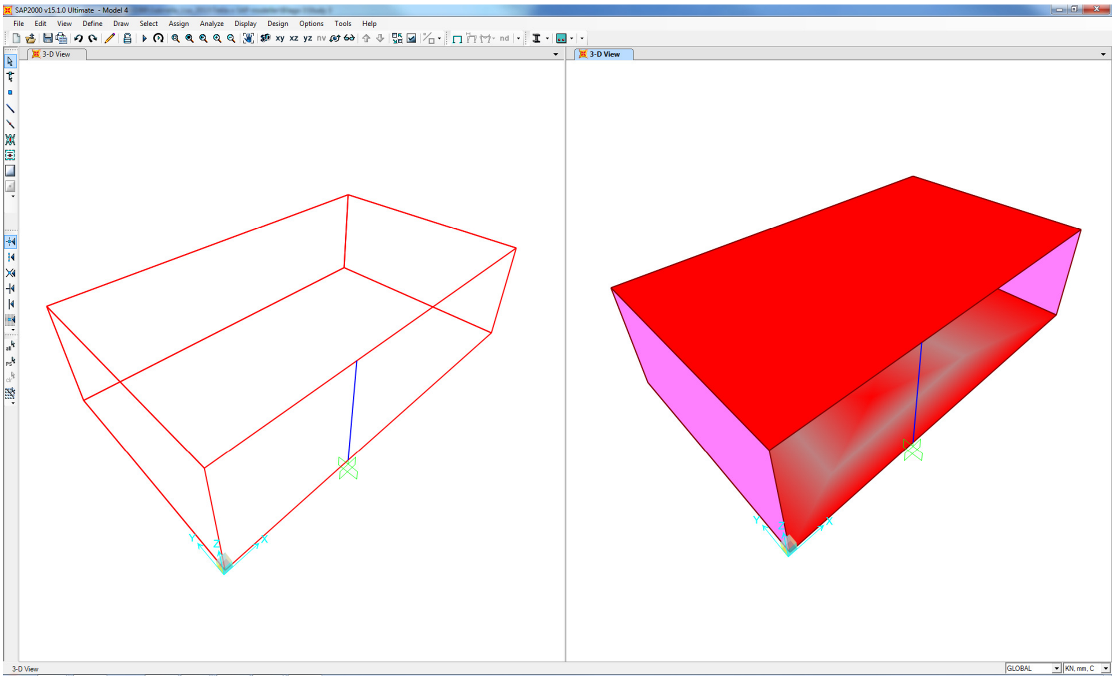
1. A model was created using the *Concrete slab, concrete panel and concrete column* tool. The modelled column is assigned a restraint in the bottom node as default in TS.



An *Analysis & Design model* was created without *warning counts*.



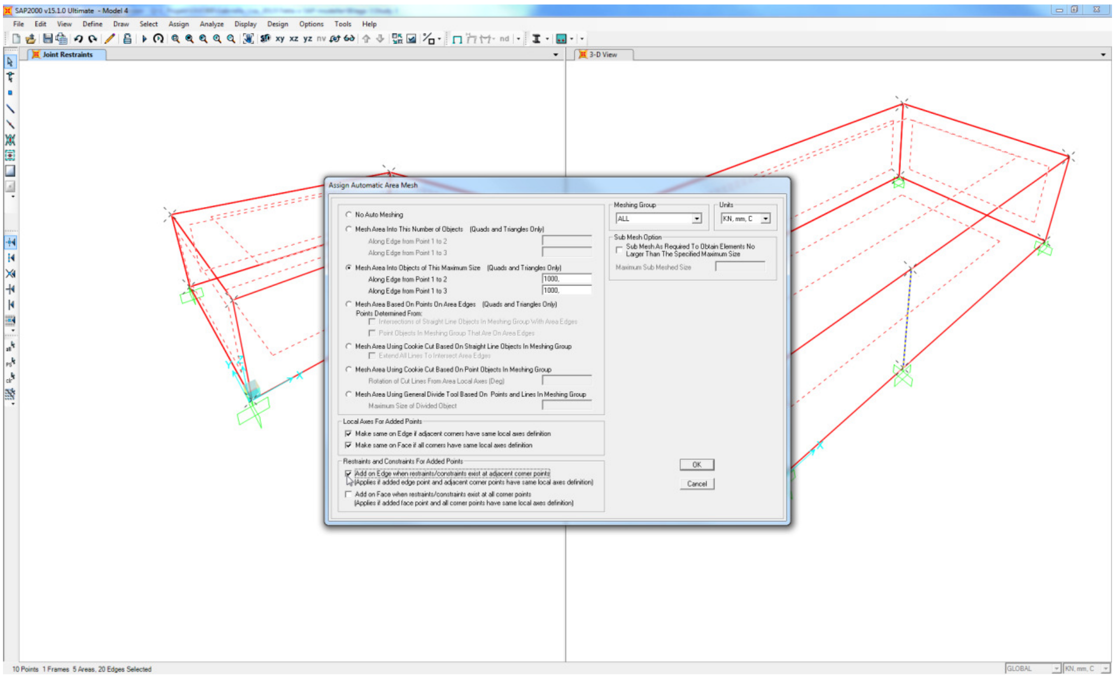
2. The model was exported to SAP and all elements were visually connected.



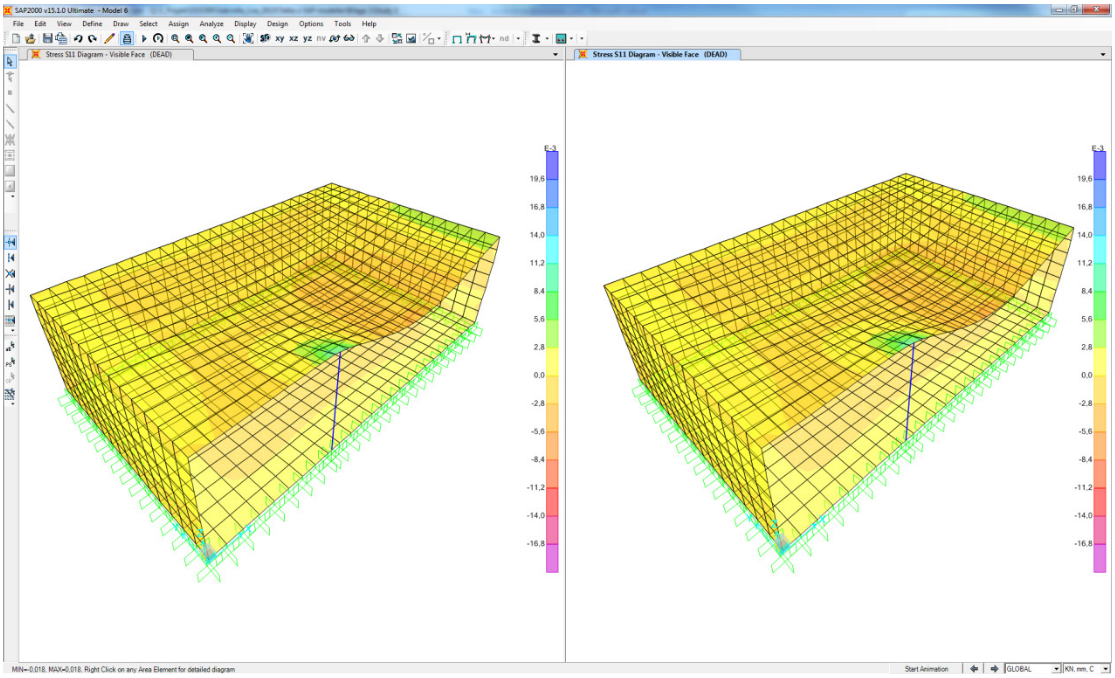
3. The corner nodes of the slab were fully restrained, including the node under the column.

4. By opening the *Assign Automatic Area Mesh* box it could be seen that the program recommend the meshing option *Mesh Area Into Objects of This Maximum Size (Quads and Triangles Only).* The maximum size chosen by the program was kept.

5. Constraints along edges of the slab were defined by choosing the option *Add on Edge when restrains/constrains exist at adjacent corner points.*



6. An analysis was performed and the result indicated that the column element and the panel and slab elements were connected.



Appendix II: Manual of the export from Tekla Structures to SAP2000

Export of panel and slab elements

Preface

Appendix II: *Manual of the export from Tekla Structures to SAP2000* is a appendix to the Master's project *Integrated work of the CAD-technician and the structural engineer*.

The master's project aims to highlight both advantages and important aspects that facilitate a more integrated working method of the CAD-technician and the structural engineer in the design phase. The Master's project focuses on the two important aspects communication and linking knowledge. The compatibility of Tekla Structure and SAP2000 is studied through a case study and by investigating the export of panel- and slab elements from Tekla Structures to SAP2000, feasibilities and limitations of the compatibility are obtained. Further on, a discussion of the feasibilities and limitaions are resulting in recommendations for the export.

The purpose of the case study was to examine the compatible link between Tekla Structures and SAP2000 through studies treating the export of panel and slab elements, openings in such elements and panel and slab elements connected to beam and column elements. A well working communication between the programs is of high importance in order to enable better coordination and integrated working method in the deisgn phase. Through the investigation of the compatibility of the software the ability of a more integrated work between the CAD-technician and the Structural engineer was studied. The result of the case study is presented as feasibilities and limitaitons for the export. Finally, the two aspects and the deeper investigated compatible software are together discussed in order to generate conclusions that facilitate a more integrated work of the CAD-technician and the structural engineer in the design phase.

The appendix aims to give a desription, step by step, of how panel and slab elements, openings in elements and panel and slab elements connected to beam and column elements can be transferred from TS to SAP. The appendix is composed from detailed printscreen pictures with a describing text. The manual is supposed to be easy to follow in order to a direct use by representavies from the industry.

In the appendix two shortnotations are used:

TS – Tekla Structures
SAP – SAP2000

Gothenburg june 2013
Lisa Beckman
Gabriella Milveden

Contents

1 Introduction

Appendix II: *Manual of the export from Tekla Structures to SAP2000* is a result from the master's project *Integrated work of the CAD-technician and the structural engineer*. The aim of the manual is to contribute to the integrated work in the design phase.

The manual describes the export of a specific model from Tekla Structure to SAP2000 with the help of the *Export* function. The export is described step by step and consists of figures and related explanations. Further on, important information and recommendations are highlighted and given continuously. The manual treats the export of panels and slabs. To read instructions about the export of columns and beams, see Appendix I related to the bachelor thesis "*Integrerad arbetsprocess mellan projektör och konstruktör*" by Nilsson and Svennered.

The manual treats the export of the following parts:

- Several connected panel and slab elements
- Openings within a panel or slab element
- Openings at the edge of a panel or slab element
- A column element connected to slab elements

Other observations from the master's project concerning the export, which are not described with the model, are presented in a final section in the end of the manual.

The model used in the manual can be seen in

Figure 1.

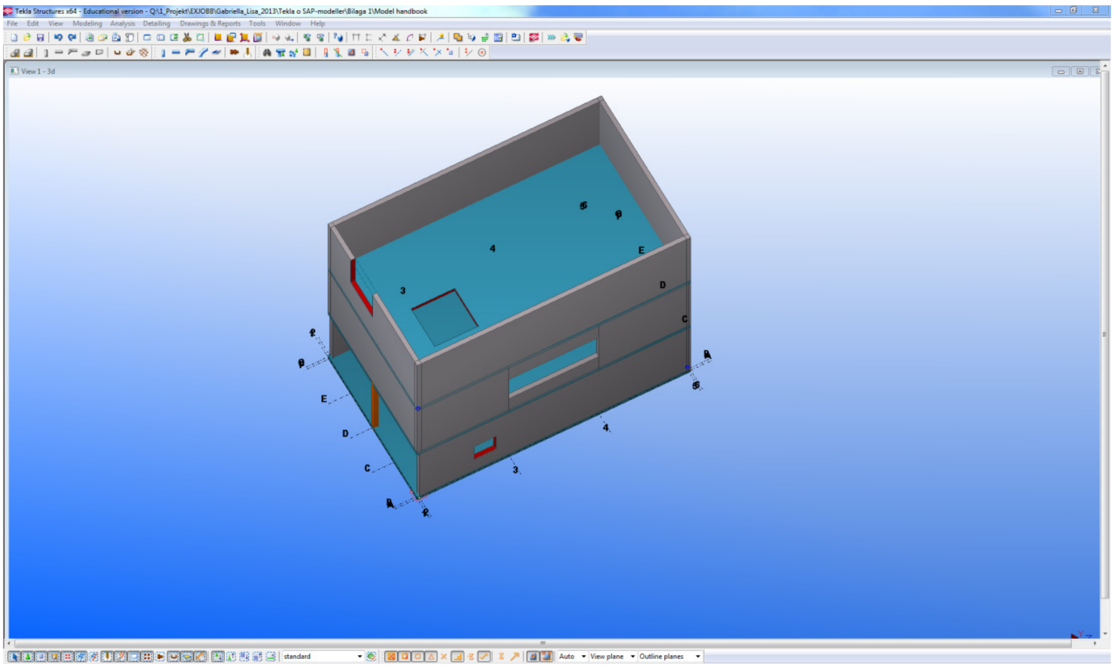


Figure 1. The used structure modeled in TS.

1.1 Conditions

In order for the manual to be useful the user needs to accomplish following conditions before usage.

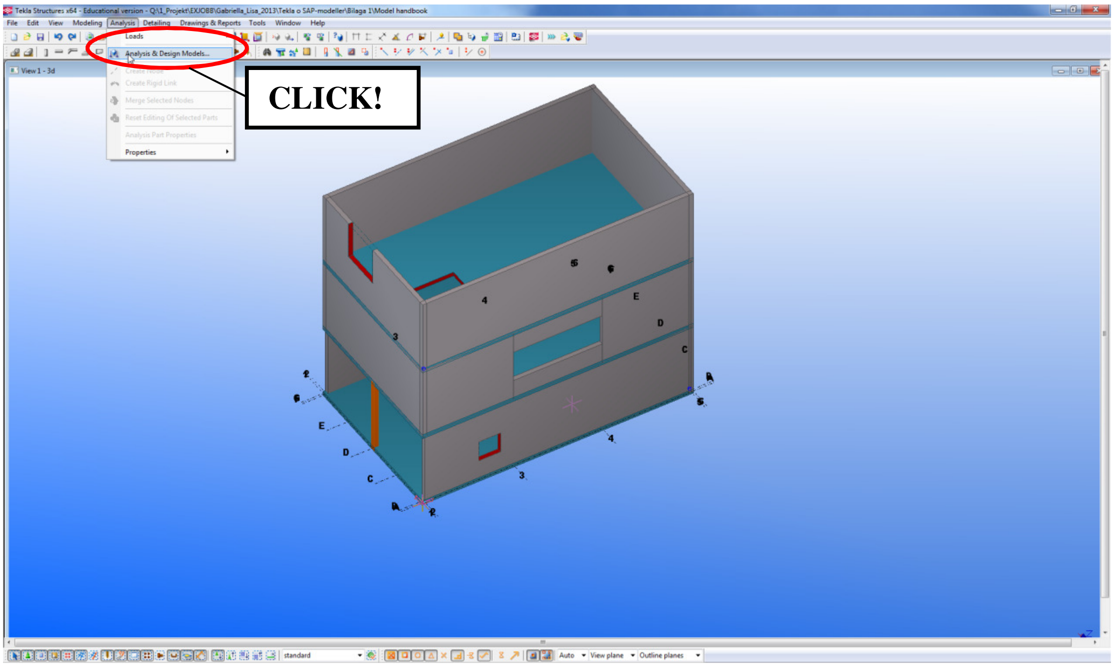
- Tekla Structures and SAP2000 needs to be installed on the same computer.
- The *Export*-link needs to be downloaded from Tekla Extranet and installed on the used computer.

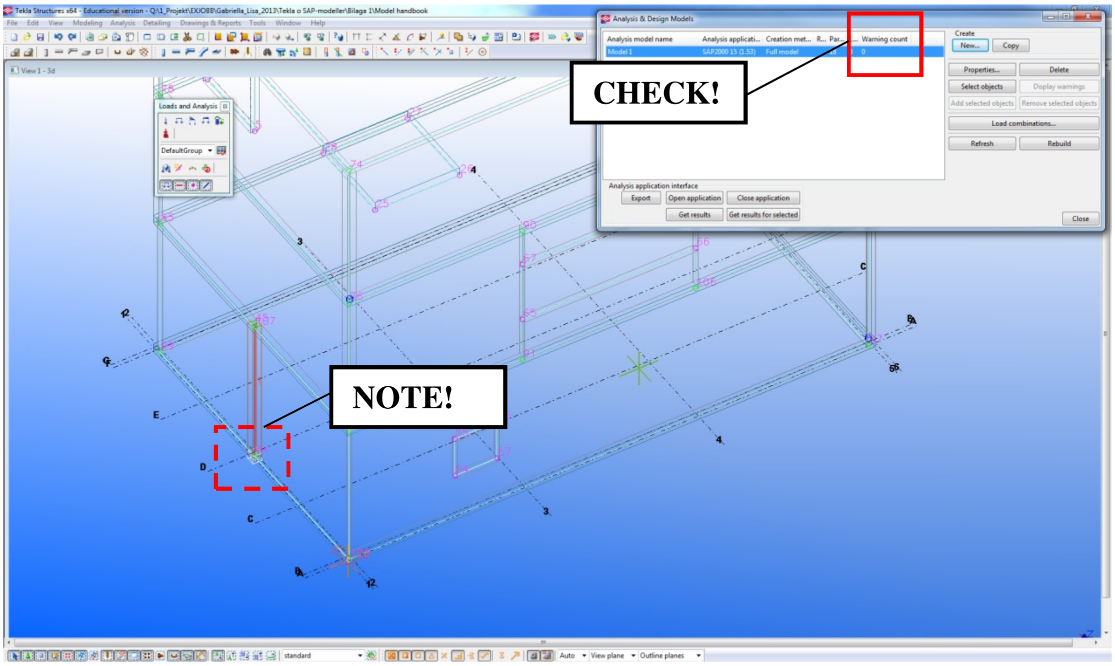
For further background and conditions for the case study refers to the master's project *Integrated work of the CAD-technician and the structural engineer*, Chapter 3 "Case study: Compatible link between software".

1.2 Modelling method

- Material properties and thickness are assigned to the elements.
- The following modelling techniques are used for creating the model: *concrete panel*, *concrete slab* and *concrete beam*.
- The model is created with elements connected in the centre line.
- The following modelling techniques are used for creating openings in the model: *Cut part with component ("Hole generation 32"), cut part with polygon* and panels modelled forming an opening.

1.3 Instructions for the layout



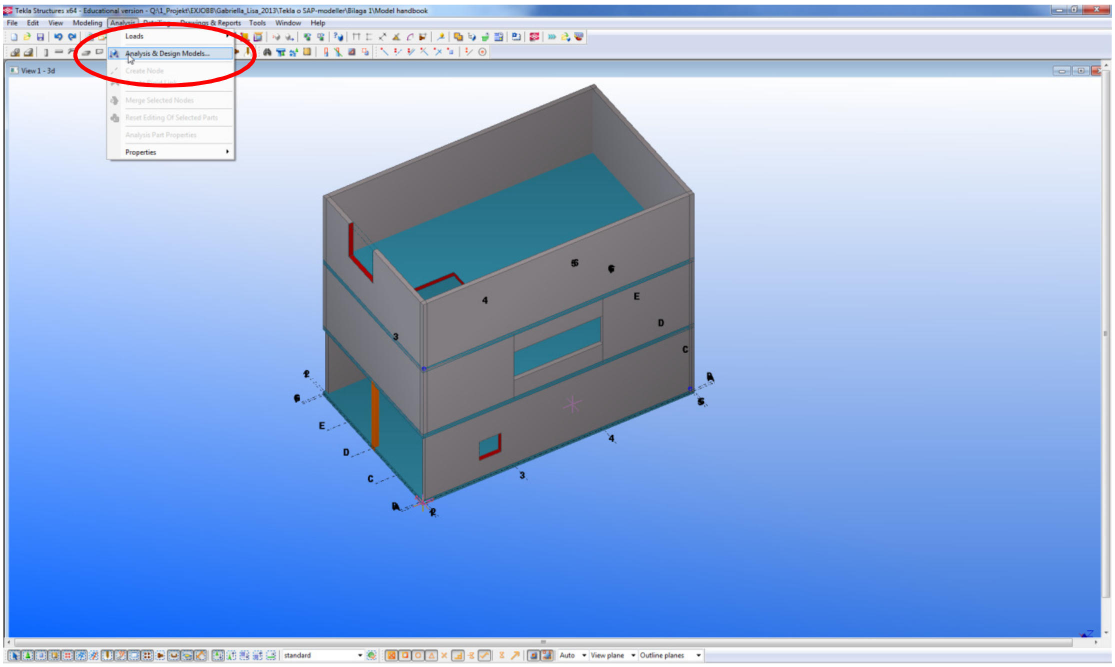


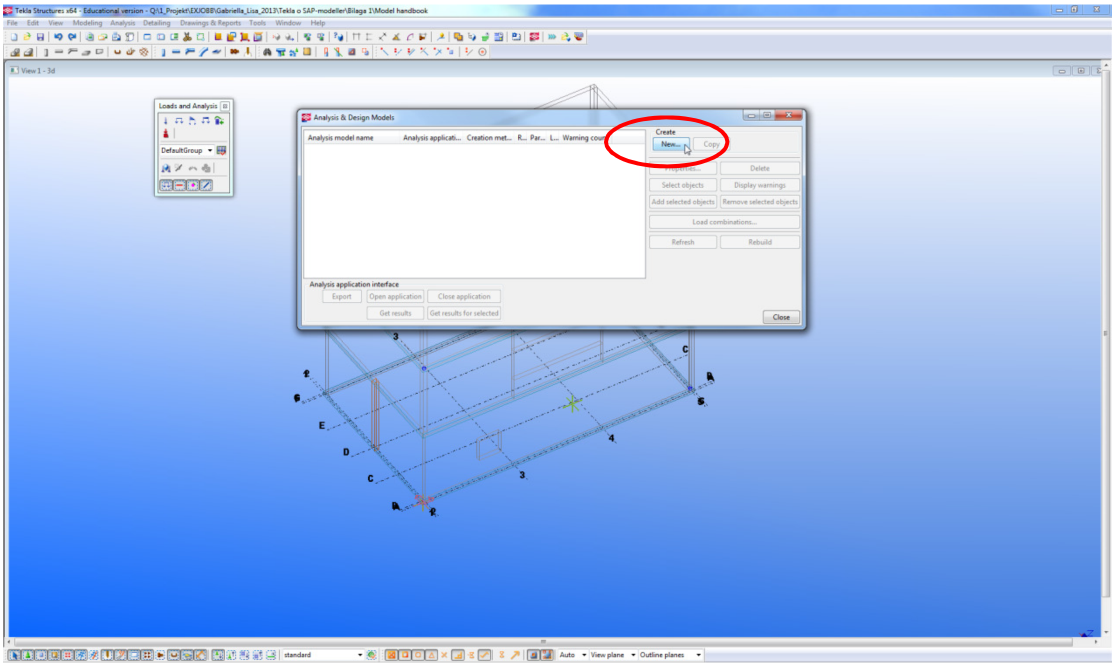
- The list gives explanations to the figures.
- It also gives further instructions which are not included in the figures.

The black textbox gives recommendations and makes the user aware of important occurrences.

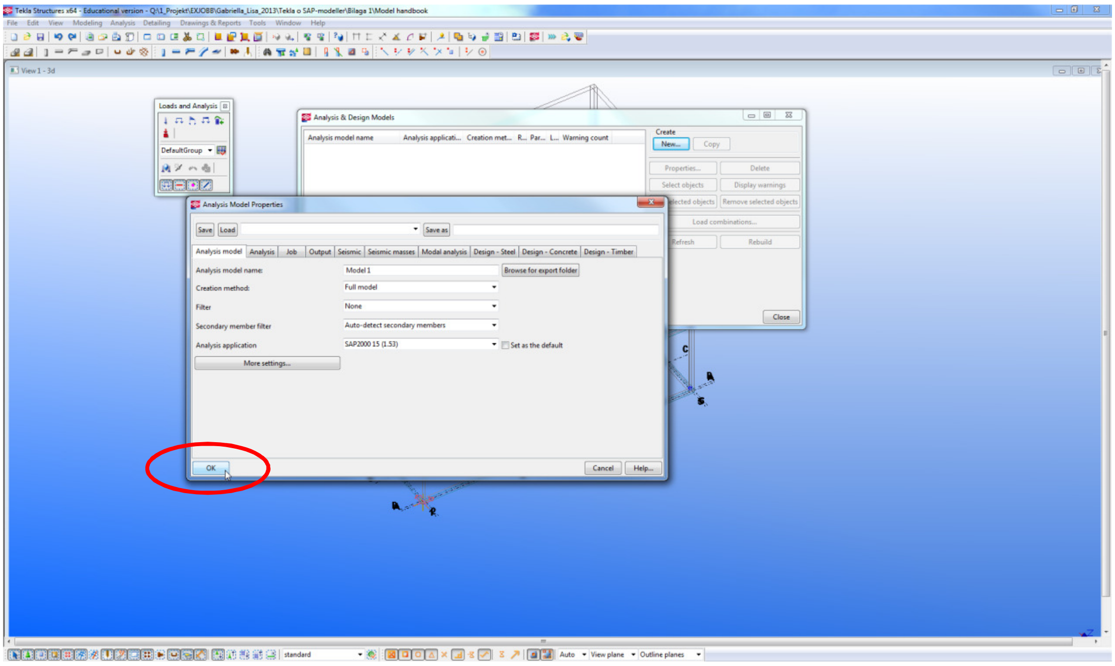
2 Handbook

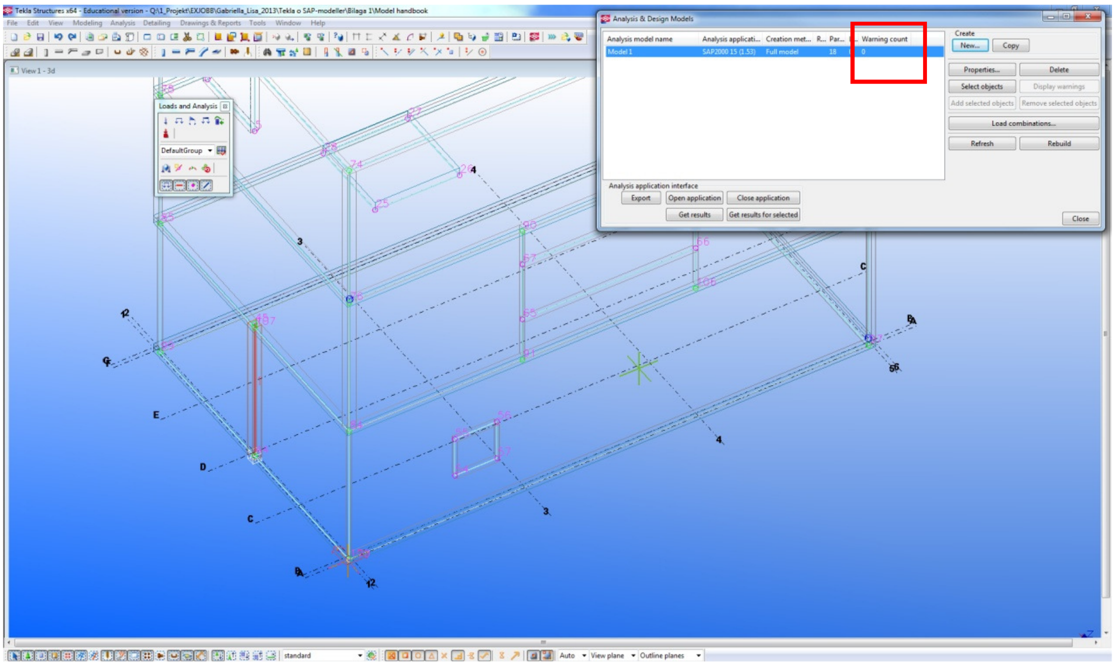
2.1 Creation of an analysis and design model





- Open a model.
- Open Analysis & Design models – Select *Analysis* > *Analysis & Design models.*
- Create a new Analysis & Design model – Click *New.*

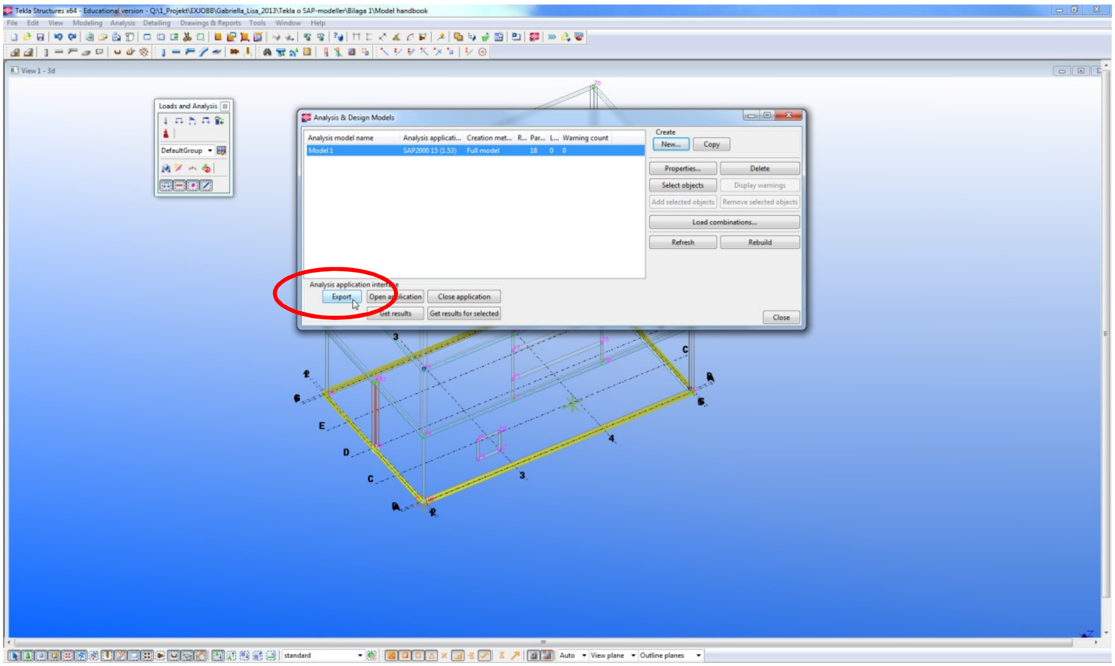


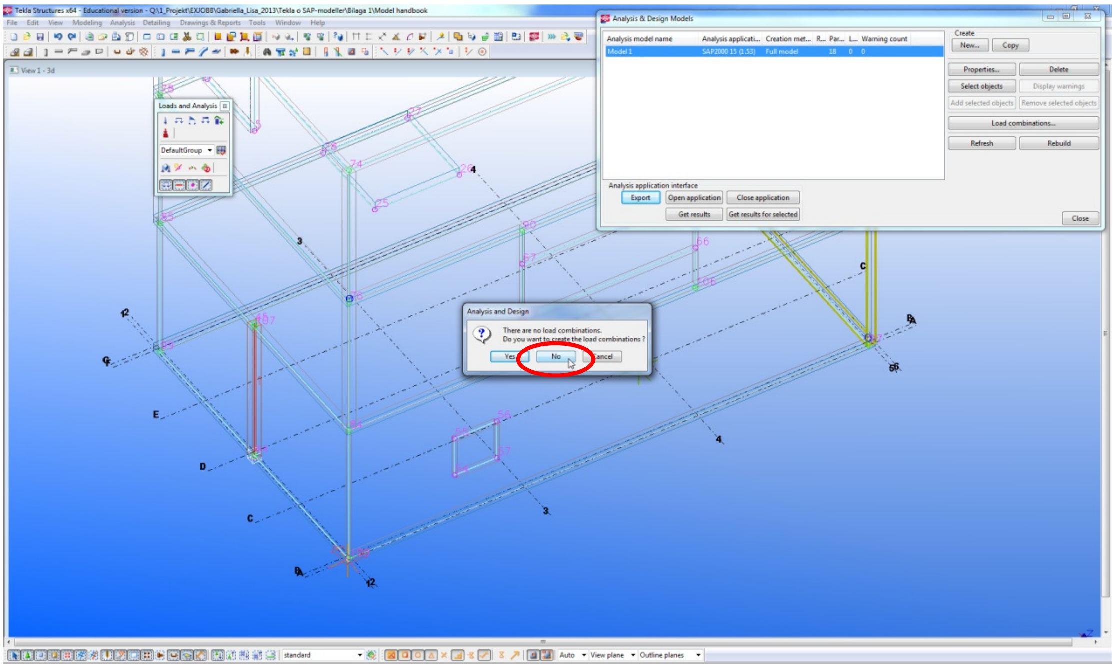


- Accept the settings to create the analysis and design model.
- Check the creation of the analysis lines and nodes by checking the *Warning count.*

The analysis line in the A*nalysis & design model* in TS is translated to a symmetry line in SAP through the export. It is therefore of importance to <u>always</u> study and check the created *Analysis & design model*. Elements aimed to be connected in SAP must share an analysis line in TS in order to be exported as connected elements. Note that, the dimensions of the model in SAP depend on the creation of the analysis lines. It is important to check possible warnings, in the column of *Warning count,* that might arises during the creation of the model.

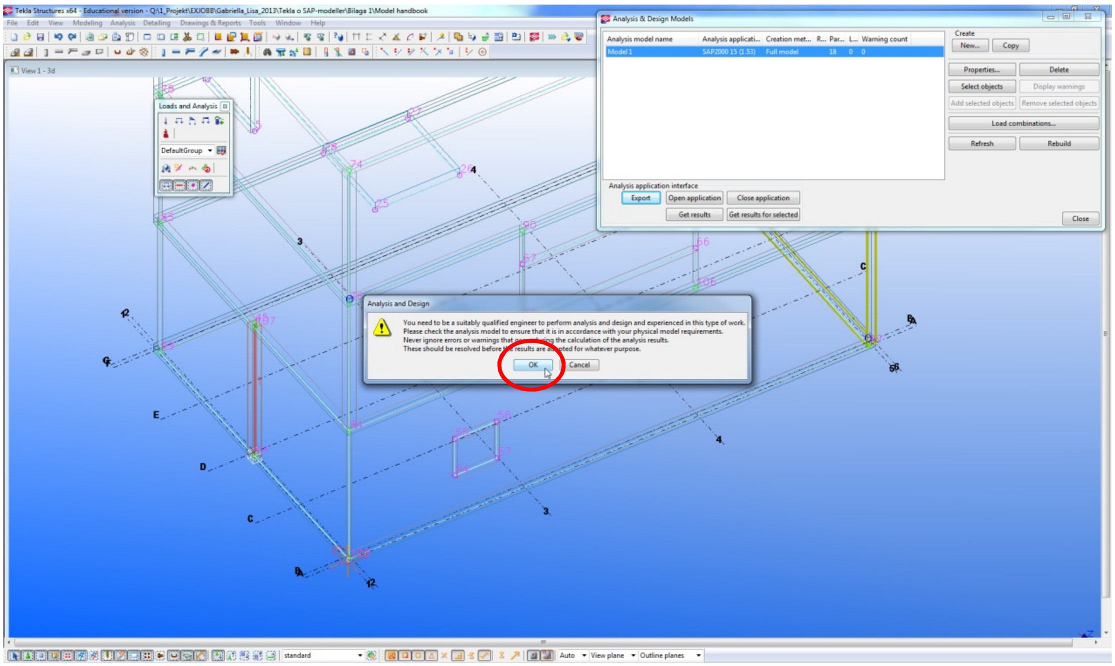
2.2 Export of model

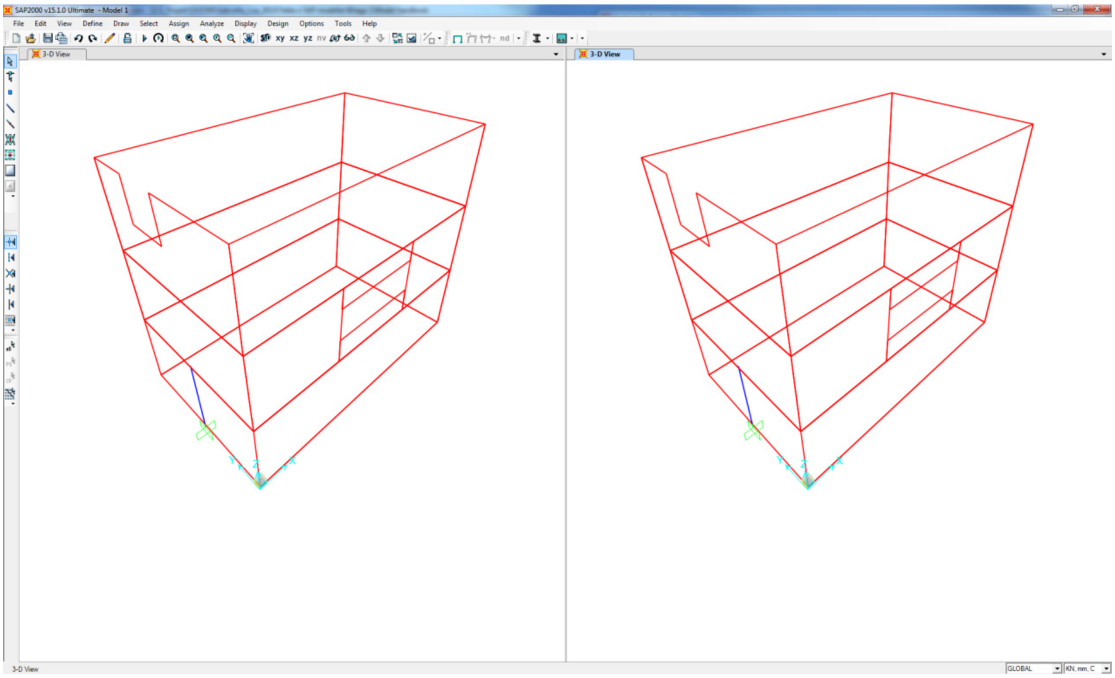




- Make sure that SAP2000 is closed.
- Export the model – Press *Export.*
- Do not create any loads in TS – Press *No.*

Loads and boundary conditions are recommended to be applied by the structural engineer in SAP. SAP must be closed in order for the export to work, otherwise a message appears informing that SAP is opened and the model is not exported. Note that the modelled column is assigned a restraint at the bottom node as default in TS. This restraint is kept for this export.

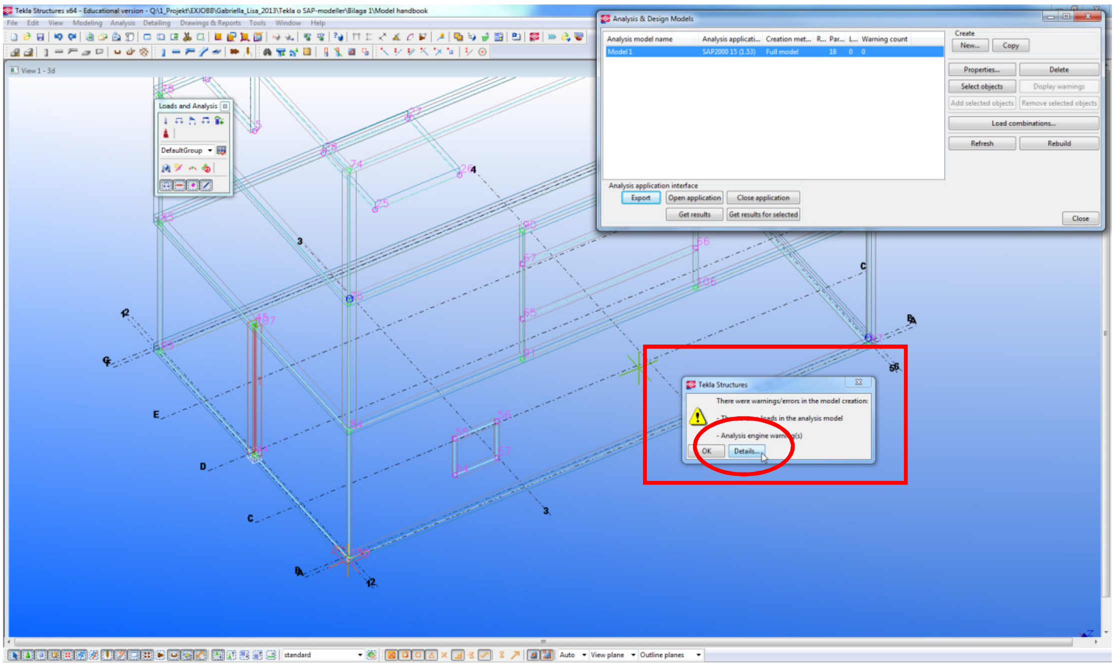


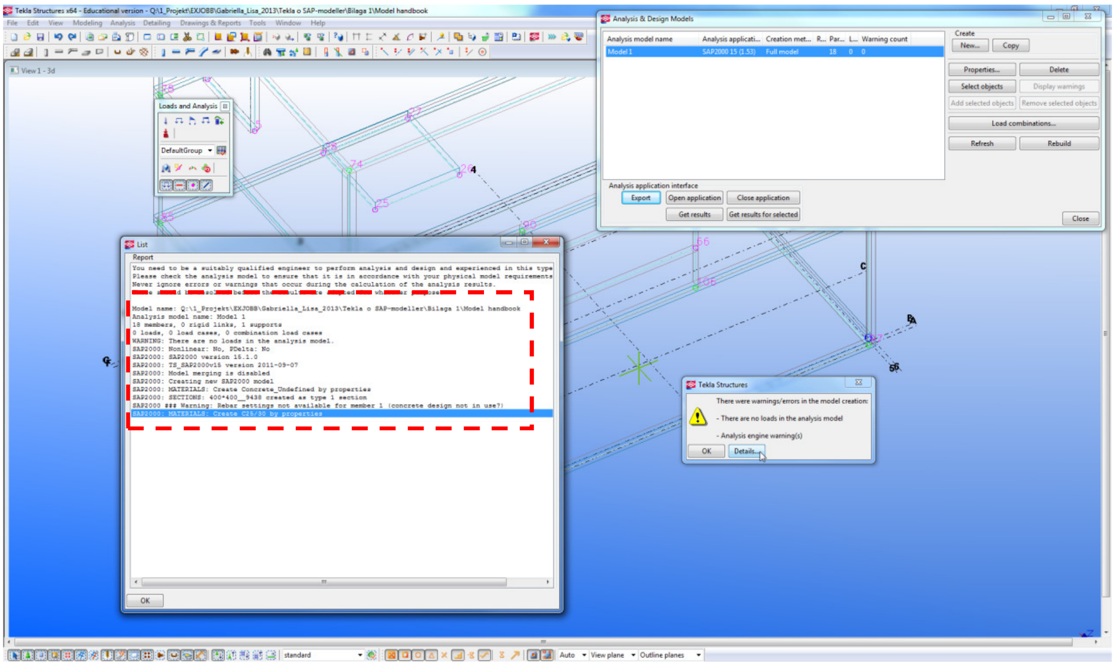


- The user must be a qualified engineer to proceed – press *OK*.

SAP is automatically opened when the Export-link is used.

2.3 Check of warning messages in Tekla Structures

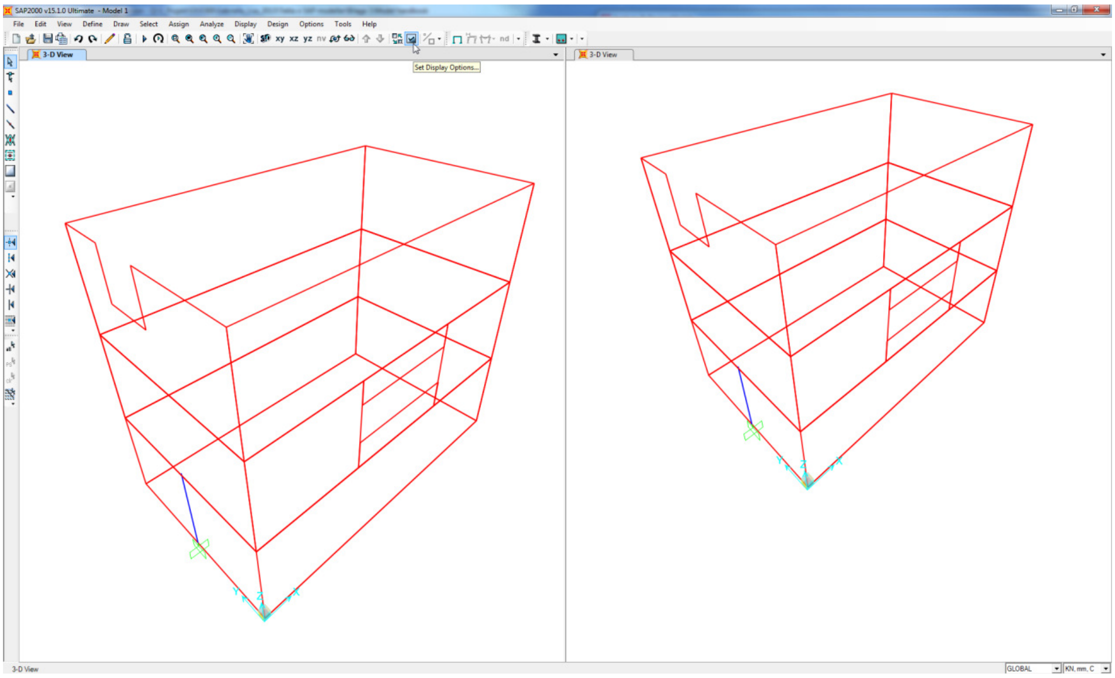


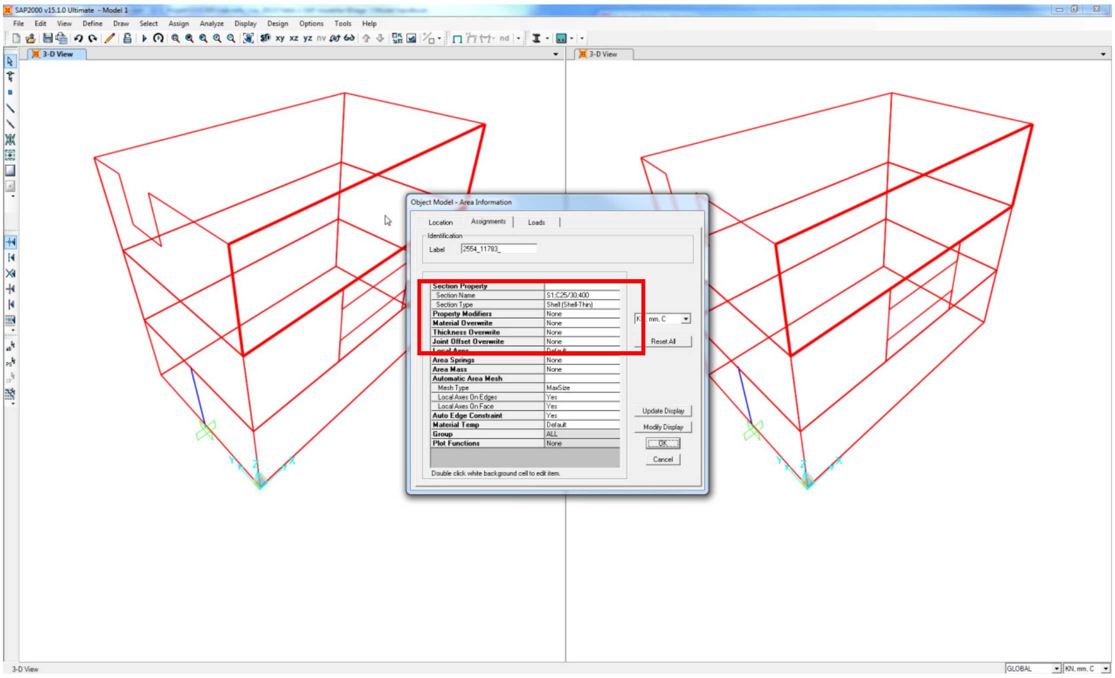


- Minimize the SAP2000 window.
- Check the *warning/errors*
- Read the detailed information about the warning/errors – click *Details*

Since SAP is automatically opened it is important to remember to always check the warnings created during the export, displayed in TS. This could easily be missed as SAP is opened in front of TS.

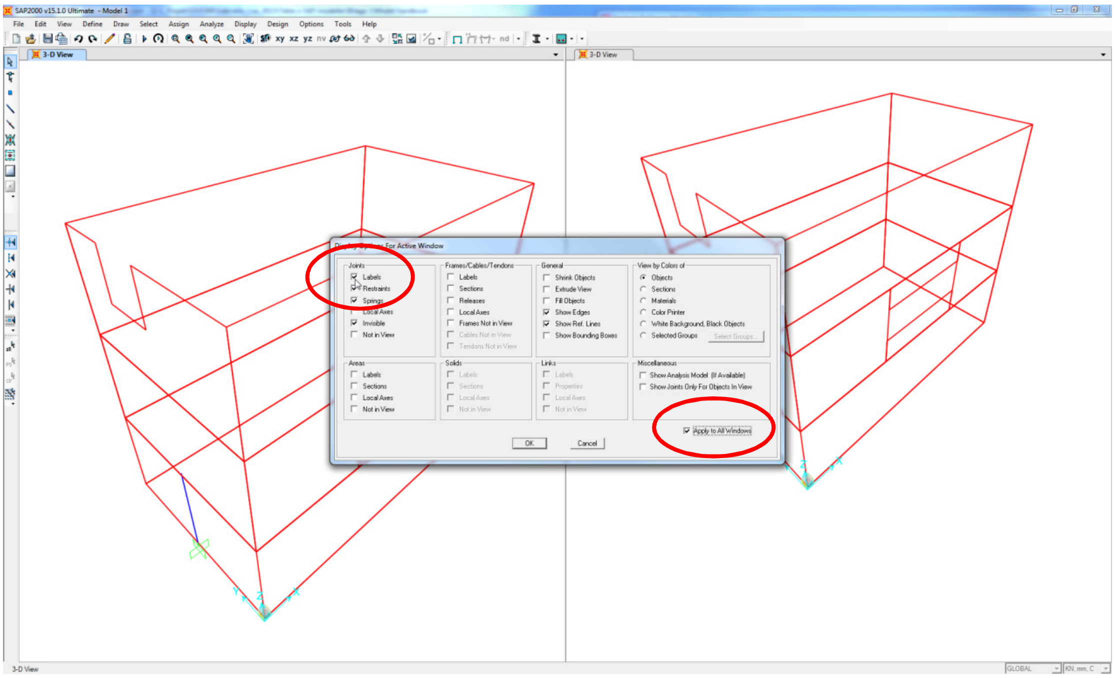
2.4 Check of exported model in SAP

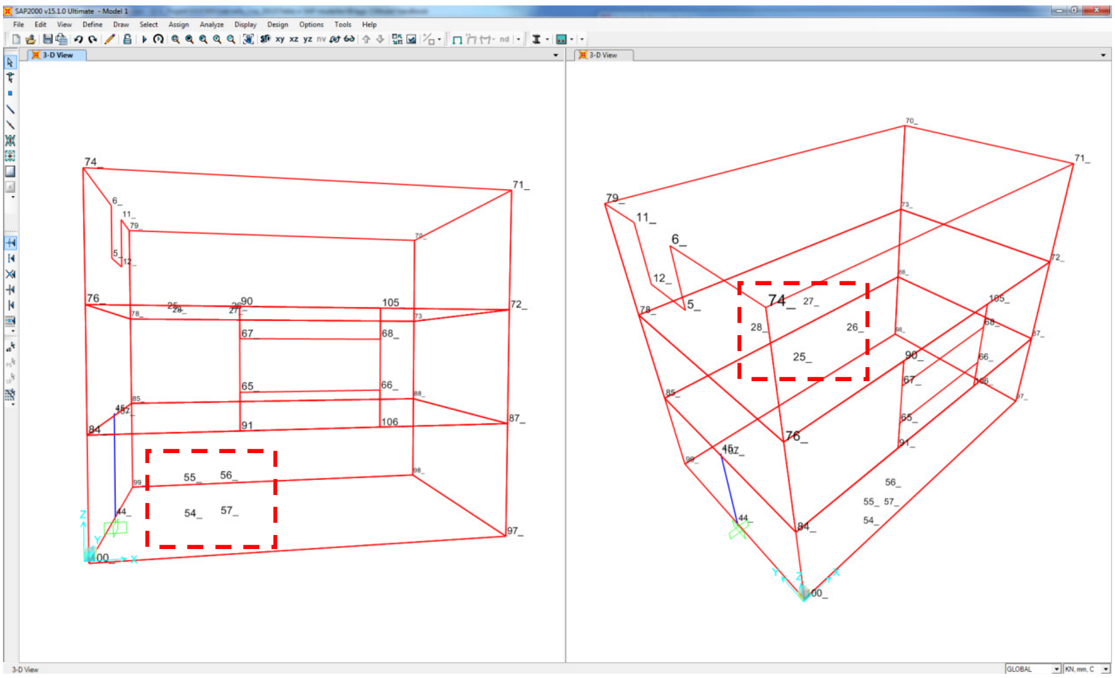




- Check the symmetry lines and nodes in the exported model.
- Check the properties of the elements – Select an area and right click.

Note that the opening at the edge and the opening formed with smaller panel elements are exported while the opening within the panel and the slab are not exported. The restraint assigned to the bottom node of the column in TS is exported. Further on, the material and thickness of the elements are exported.

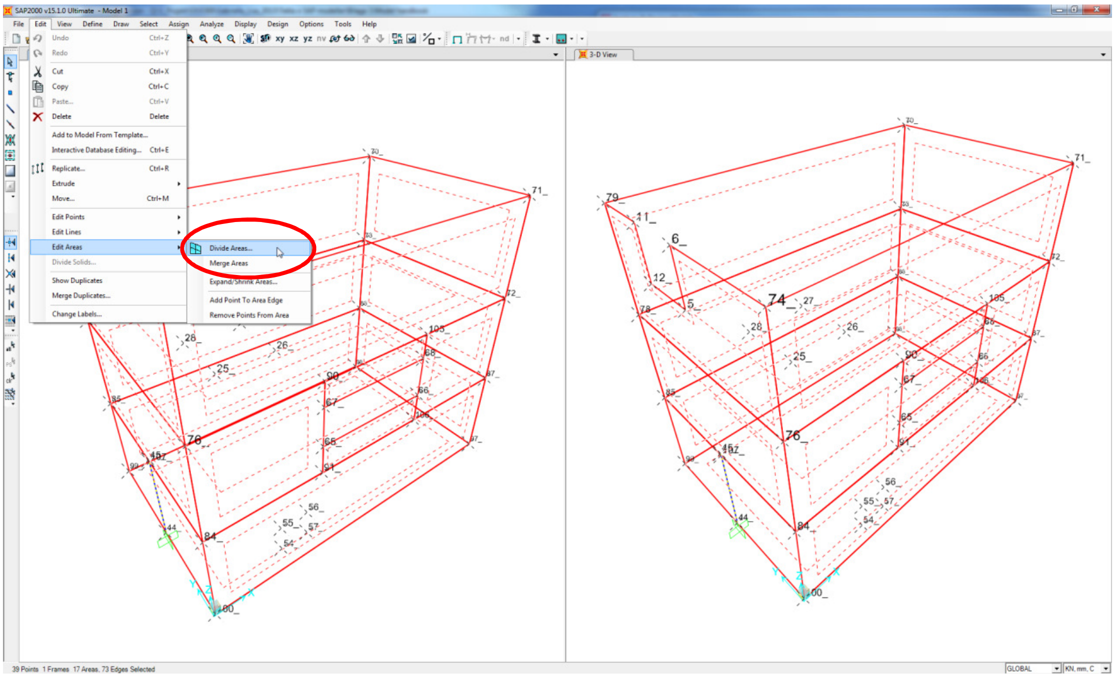


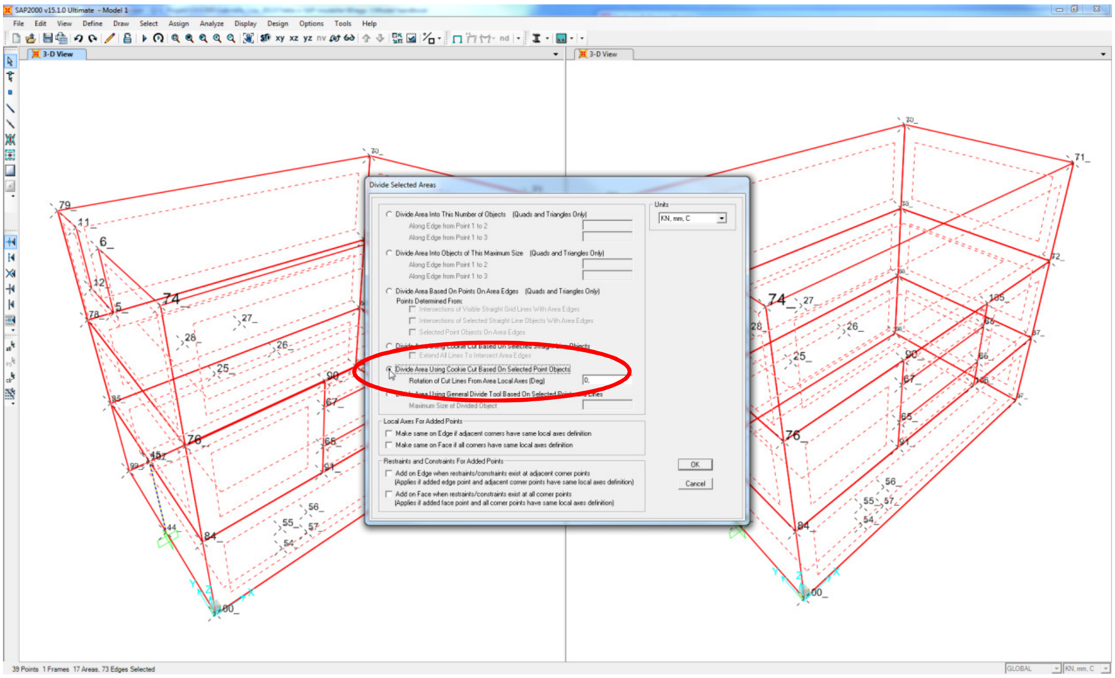


- Open the display options – Go to *View* > *Set Display options*> *Display* Options For Active Window.
- Display internal joints graphically in all windows – select *Labels* and *Show to all windows.*

The nodes of the openings are exported and the numbering in SAP matches the numbers defining the opening in TS. By showing these numbers in the model it is possible to find the openings which are not exported.

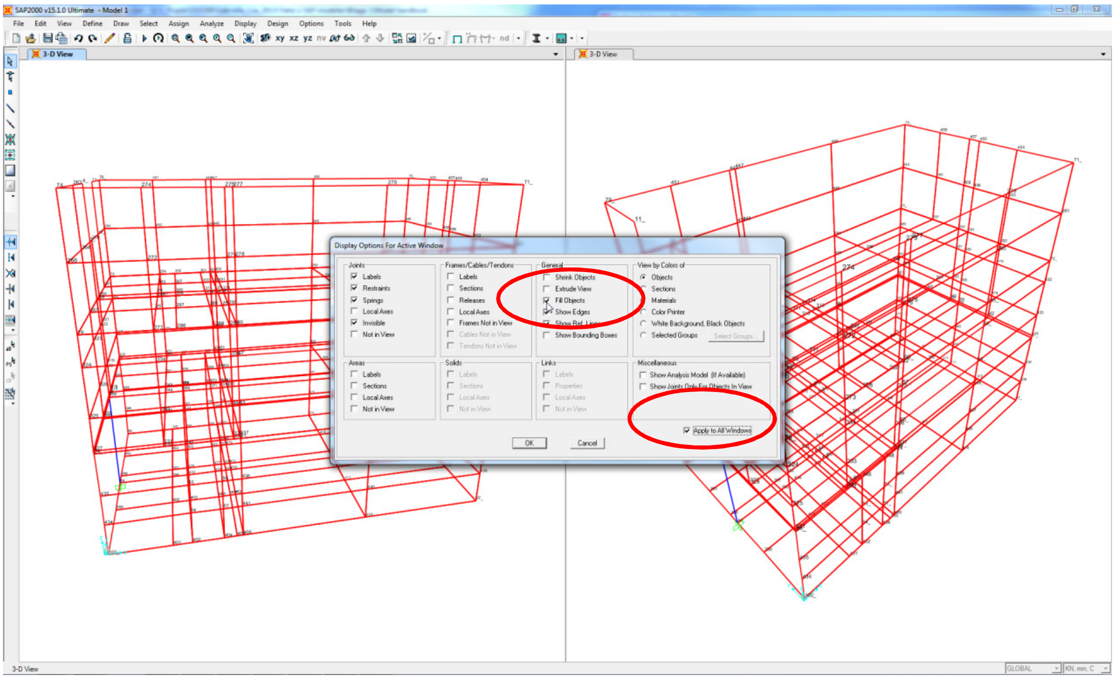
2.5 Creation of non exported openings in SAP

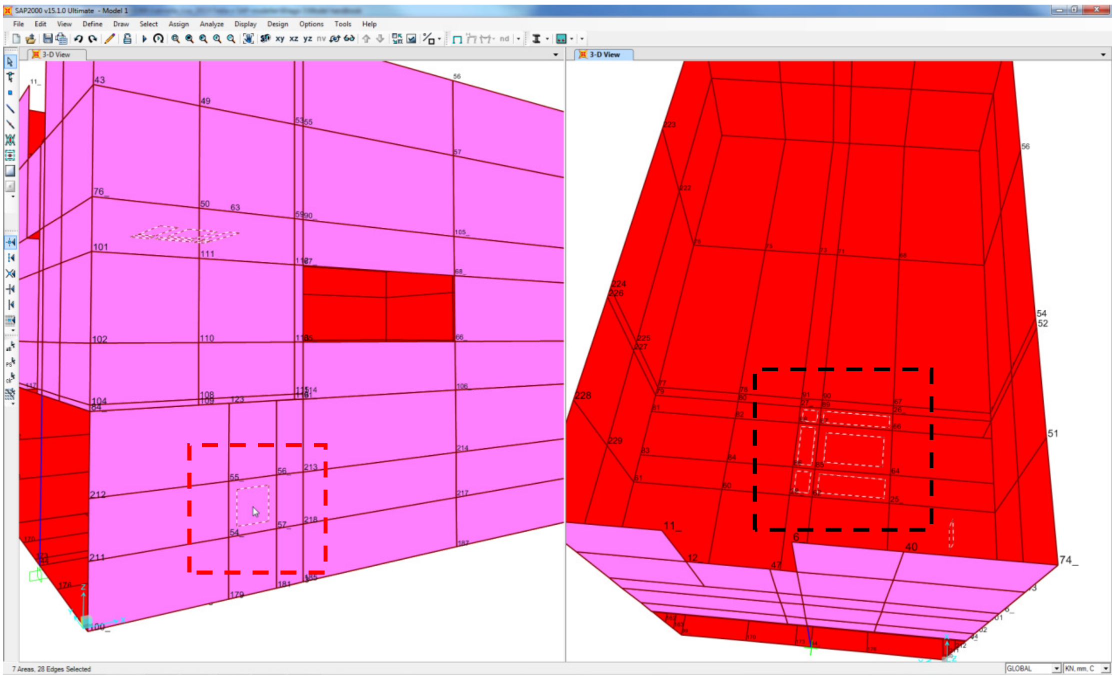




- Select the entire model.
- Open the Divide selected area box– Select *Edit > Edit Areas > Divide Areas.*
- Divide the area based on selected points – *Select Divide area using cookie cut based on selected points objects.*

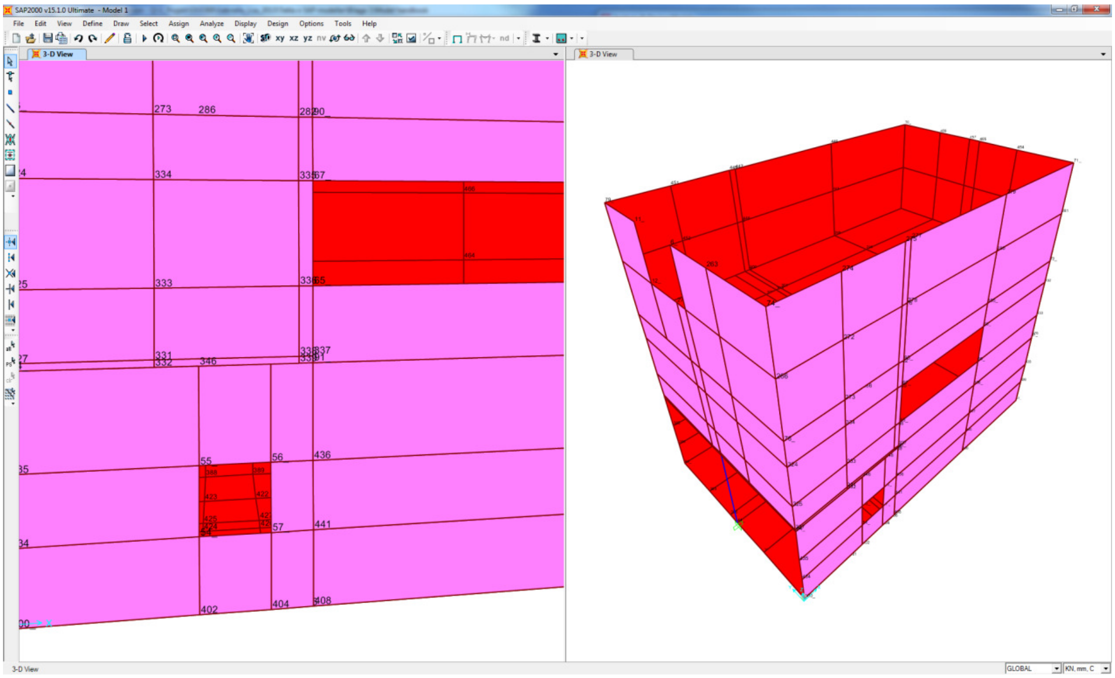
In order to create the openings in SAP, which are not exported, the model must be divided into smaller areas. The division must be based on <u>all</u> nodes in the model.

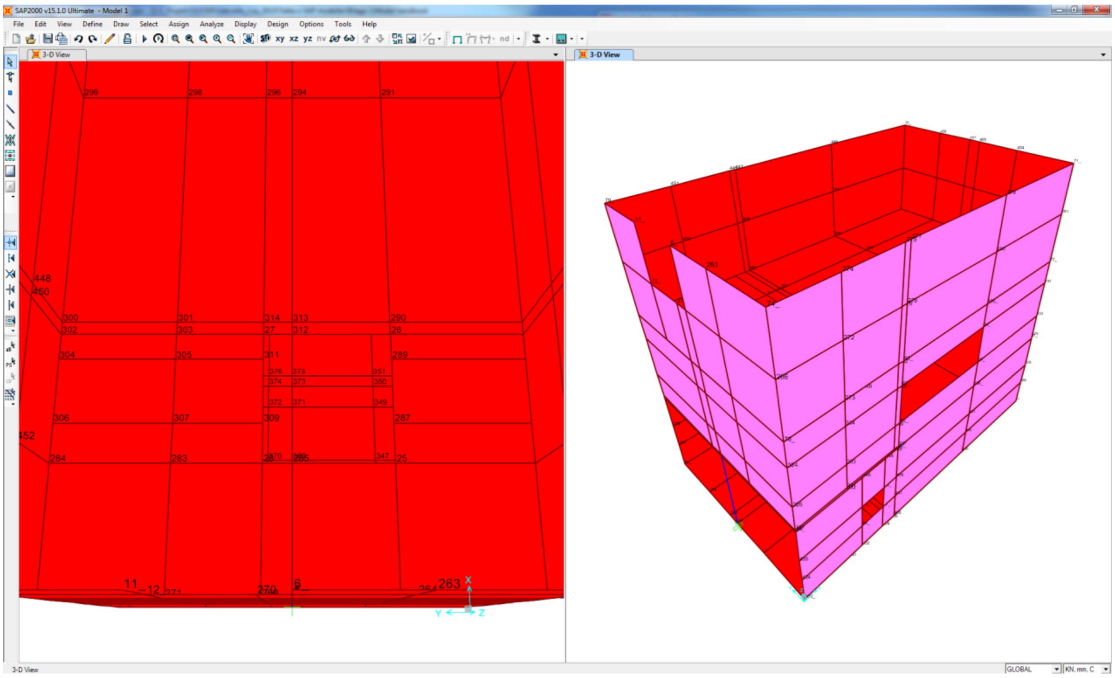




- Open the *display options for active window* box – select *Display > Set display option.*
- Show filled objects in all windows – select *Fill objects* and *Show to all windows.*
- Find the nodes forming the openings and select the area by left clicking.

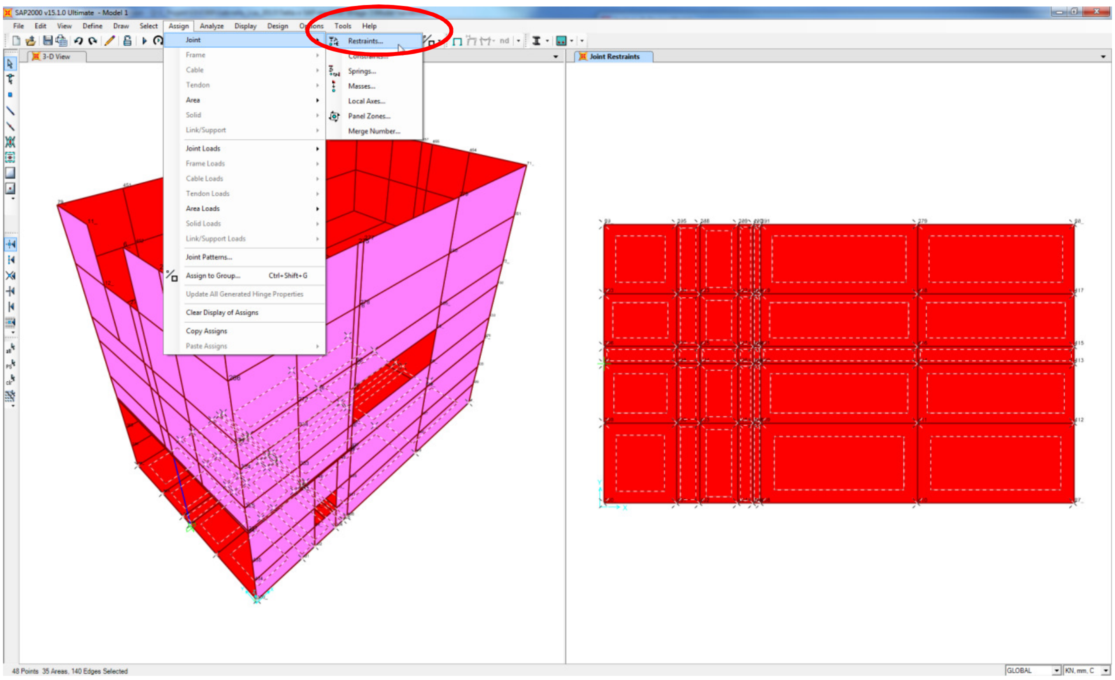
The user must find the smaller areas defining the opening with the assistance of the numbered nodes.

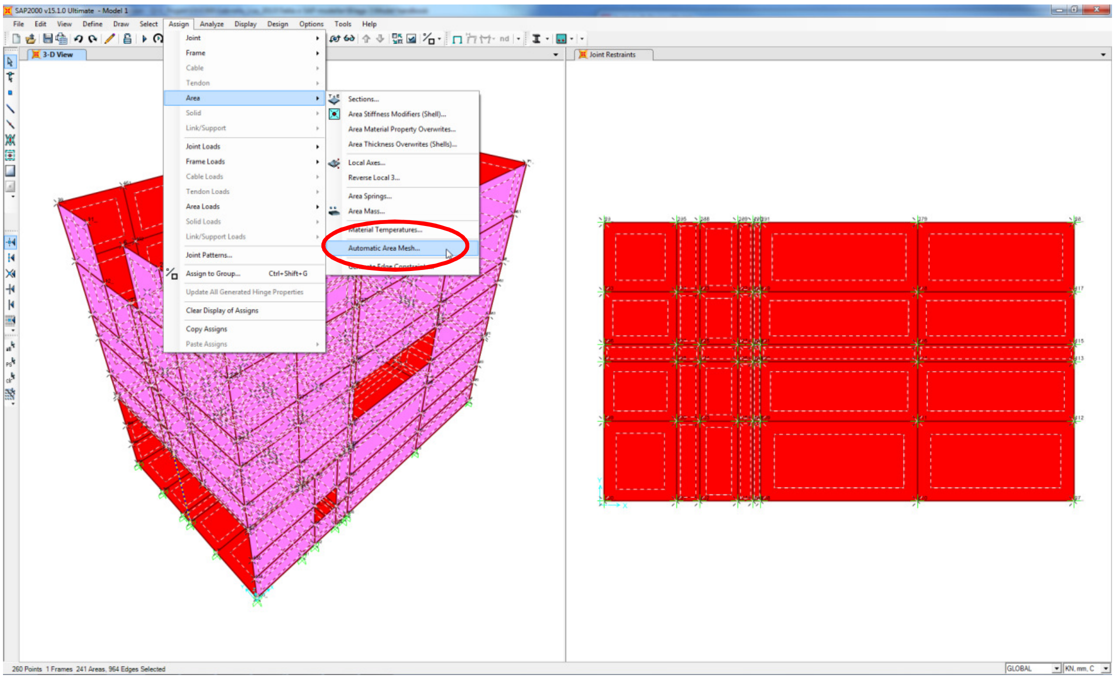




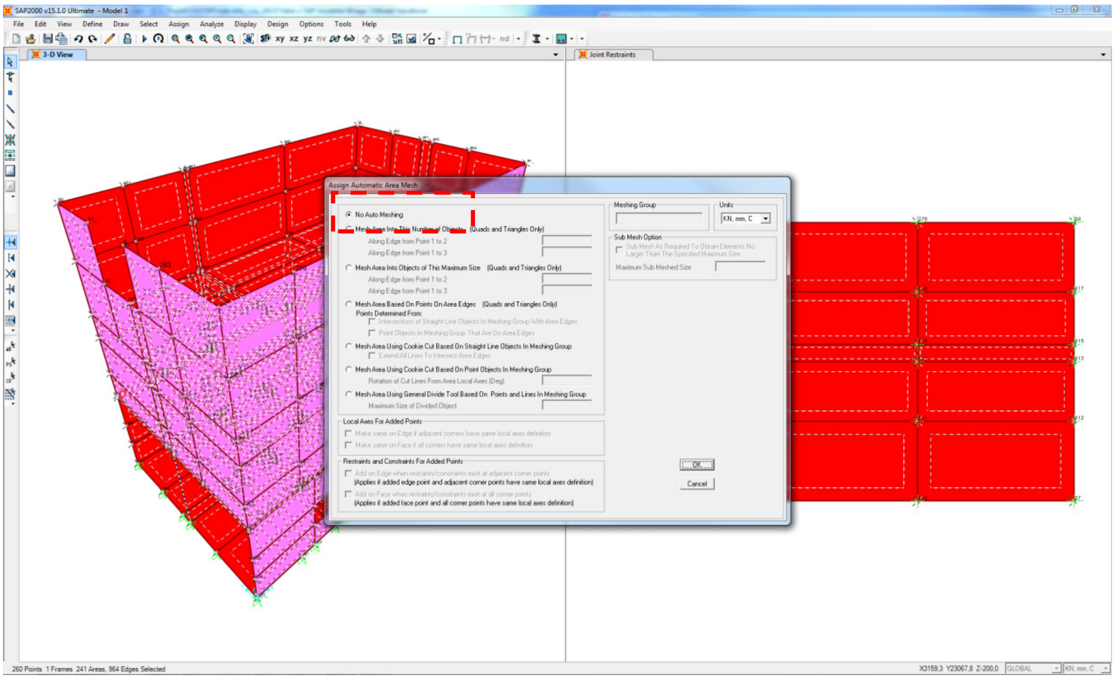
- Press the *delete* key in order to erase selected parts and to create the opening.

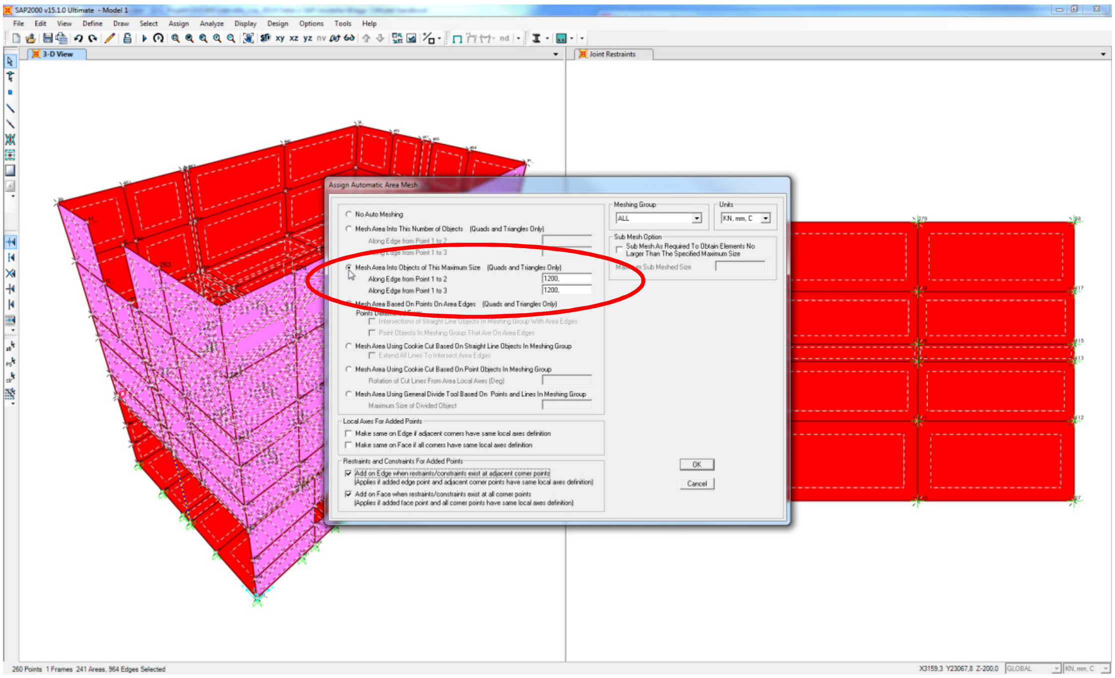
2.6 Definition of boundary conditions and choice of mesh





- Select all nodes on the bottom slab in order to define boundary conditions.
- Define restraints to the selected nodes – Use the command *Assign > Joint > Restraints.*Chose the requested typ of restraint.
- Select the entire model
- Open the Assign automatic area mesh box – Go to *Assign > Area > Automatic area mesh.*

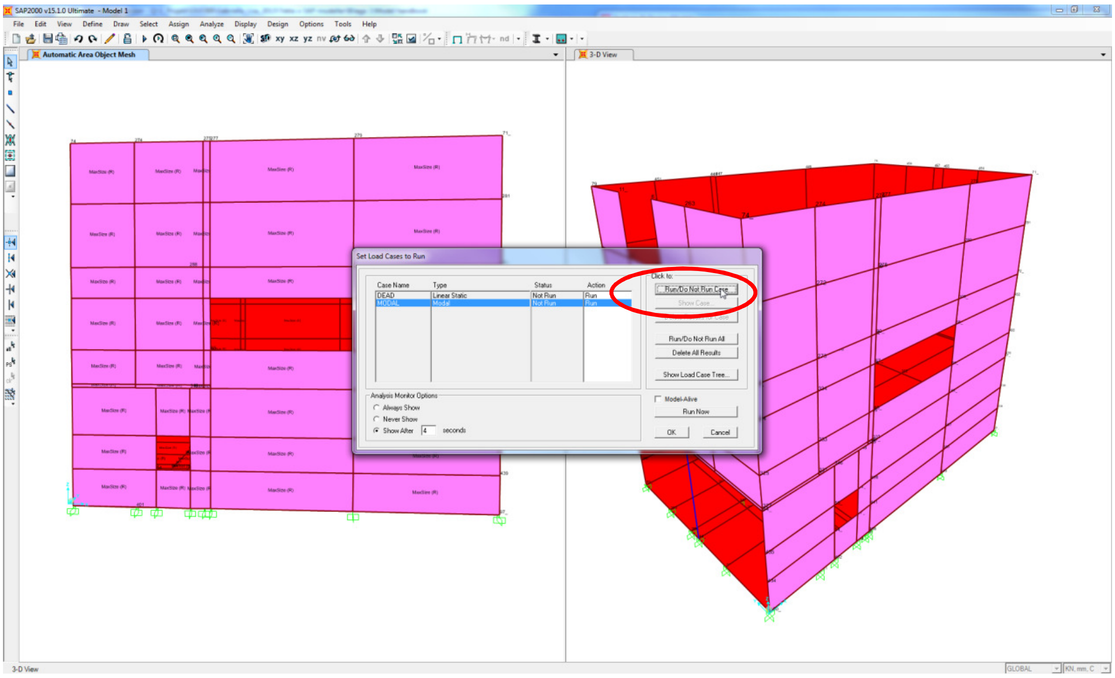


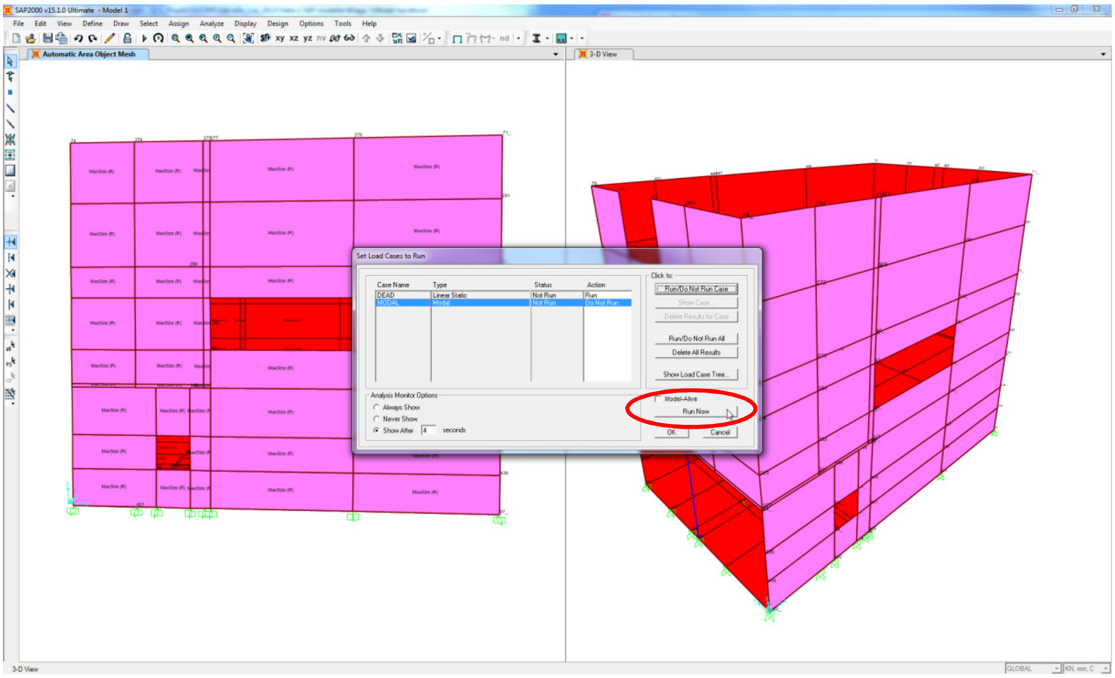


- Mesh the structure into objects with a specified maximum size – Select *Mesh area into object of this maximum size (Quads and Triangles Only)* and define a maximum size.

Note that the program always recommends no automatic mesh after using the command *dividing areas*. In order to mesh the model, another meshing option must be selected.

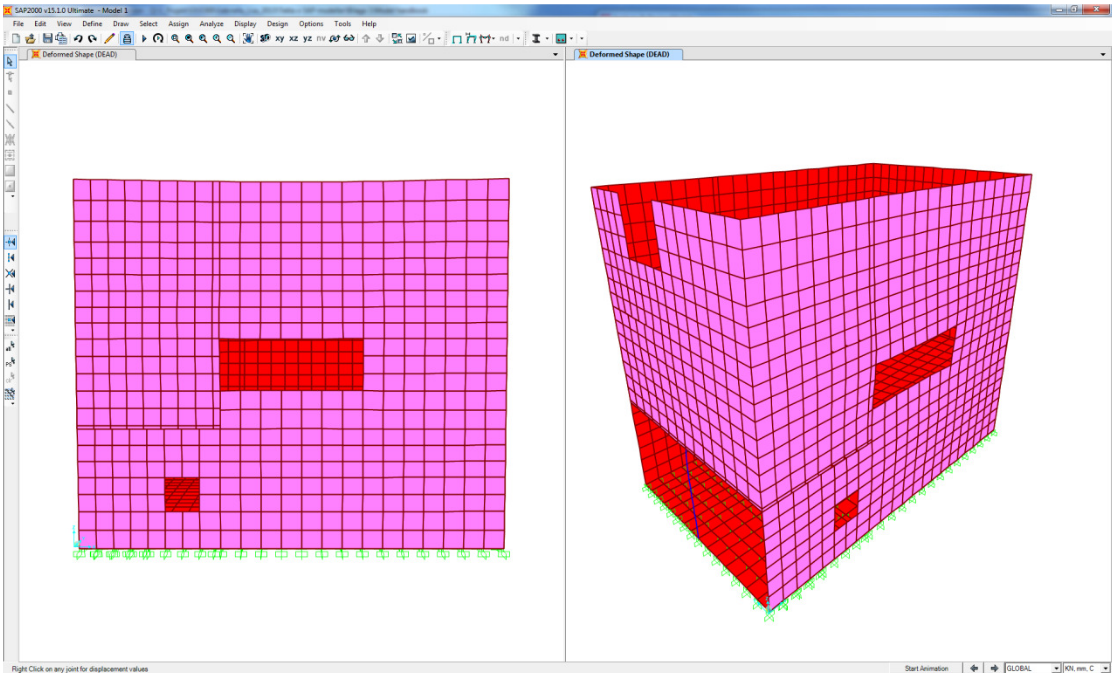
2.7 Analysis





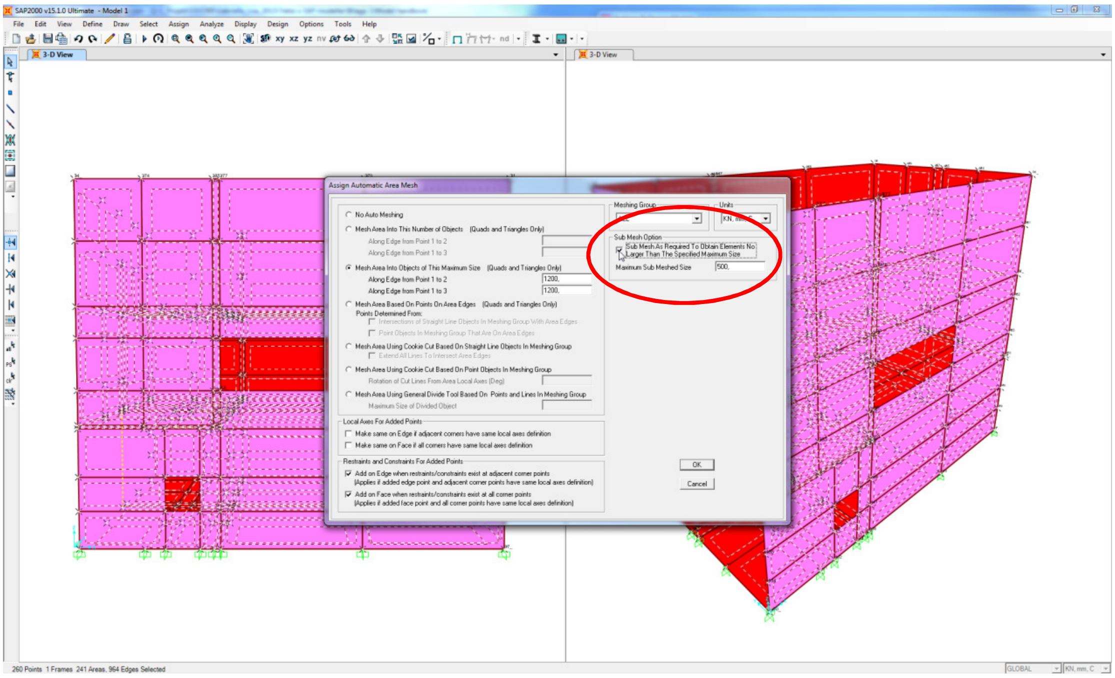
- Open the *Set Load Cases To Run* box – Go the *Analyse* > *Run Analysis*
- Run only the linear static analysis – Select the line for the modal case and click *Run/Do not run case.*
- Run the analysis – Click *Run now.*

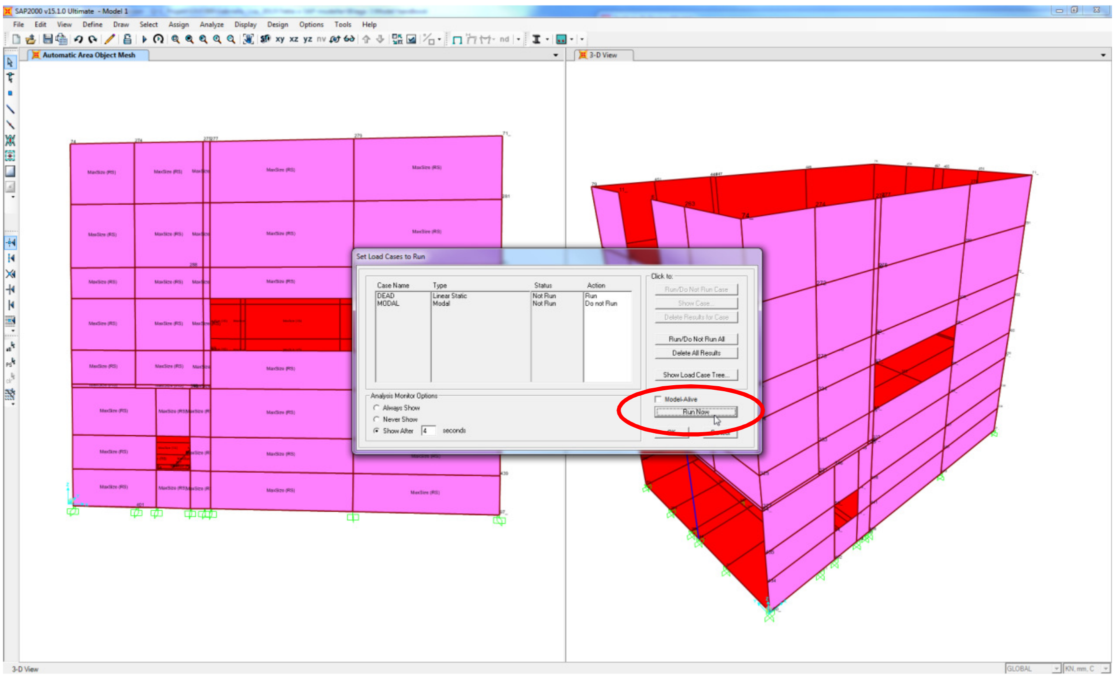
A static analysis is performed in order to see if the model is behaving as suspected.



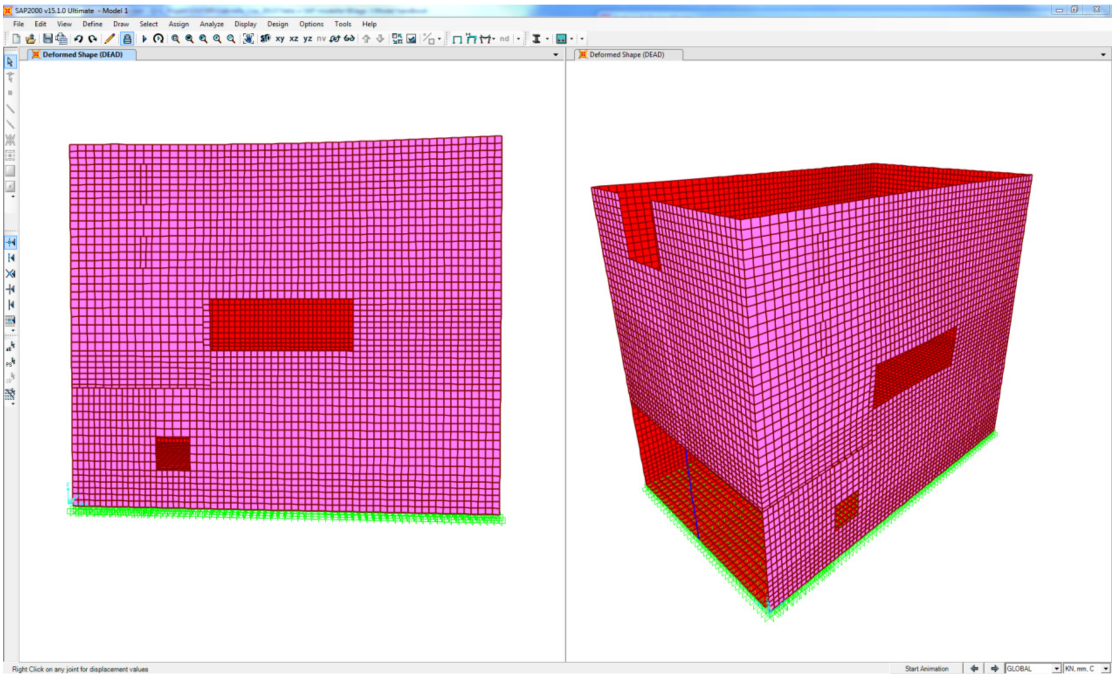
The model is analysed influenced only by dead weight and the result is displayed by a deformed shape. In order to get a more fine mesh the following steps can be included in the work (see next page).

2.8 Refining the mesh





- Choose the same meshing option as before.
- Select the *Sub mesh as required to obtain elements no larger than the specified maximum size* and define a *maximum sub meshed size*.



The model is analysed influenced only by dead weight and the result is displayed by a deformed shape. The new mesh which is generated is finer.

3 Other observations

There are a number of observations that occurred during the case study in the Master's project which are not presented in the step by step-instruction. These are collected in the list below.

- It is not possible to get a regular mesh with rectangular elements for a panel or slab which contains circular opening. Instead, as far as possible, it is suggested to model rectangular openings instead of circular openings. It is recommended for the structural engineer to erase possible circular openings to ensure a correct mesh.
- Parts which are only "partly cut out" are not exported. "Partly cut out" can be described as a part which is not totally cut through but only partly cut into the element.
- For panels and slabs without modelled openings it is possible to use the auto mesh chosen by the program.
- The modelling techniques used for creating of openings in the model are an example of techniques available in TS. It has been shown that the export of openings is independent of modelling technique.