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DESIGN HANDBOOK FOR A STACK FOUNDATION

Tekniikka ja liikenne
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Rakennustekniikan koulutusohjelma

TIIVISTELMÄ

Tekijä	Vilma Tuominen
Opinnäytetyön nimi	Stack -perustuksen suunnitteluohje
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Ohjaaja	Heikki Liimatainen

Tämä suunnitteluohje on tehty Citec Engineering Oy Ab:lle toimeksiantona. Ohje koskee Wärtsilän voimaloissa olevien n. 40 metristen savupiippujen betoniperustusta. Tarkoituksena on ollut tehdä suunnittelutyötä tukeva laskentamalli, jonka avulla suunnittelija voi tarkistaa mallin mitoituksen. Työ tulee olemaan betonirakennesuunnittelijoiden, sekä muiden suunnittelijoiden ja asiantuntijoiden käytössä.

Työssä on käytetty esimerkkimallina vanhaa perustusta, josta on tehty Staad Pro rakennemalli ja Auto Cad -piirustukset. Kuvien ja rakennemallin perusteella olen tehnyt Excel -laskentapohjan, joka määrittää perustuksen kestävyyden, kuormat ja oikeat mitat. Lisäksi olen suorittanut kuormitus- ja voimalaskennat käsin ja verrannut niitä Staad Pro -mallin vastauksiin.

Työn tuloksena on tarkoitus syntyä perusasiat sisältävä suunnitteluohje, jossa on mukana laskentapohja perustuksen suunnittelua ja tulosten vertailua varten. Suunnitelma on tehty Eurocode -standardien mukaisesti.

Avainsanat perustus, laskentapohja

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ABSTRACT

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This thesis was made for Citec Engineering Oy Ab as a handbook and as a design tool for concrete structure designers. Handbook is about the Wärtsilä Power Plant stack structure, which is a base for about 40 meters high stack pipe. The purpose is to make a calculation base to support the design work, which helps the designer to check the right dimensions of the structure. Thesis is about to be for the concrete designers and also other designers and authorities.

As an example I have used an old model of a structure which has a Staad Pro model and drawings made with Auto Cad. Based on the drawings and structural model, I have created an Excel base which defines the forces and the loads and the dimensions of the structure. I also compared the Staad Pro calculations and handmade calculations.

As a result of this work is a handbook which includes the basic knowledge and also a calculation base to help designing and also for comparing different results. The handbook has made by Eurocode standards.

Keywords foundation, calculation base

CONTENTS

1 INTRODUCTION

1.1 General information

This work is going to be a handbook for concrete structure designers in Citec Engineering. As a handbook, it will also be supportive guide for all structure designers. The handbook comprises the basic knowledge of a stack structure and how it’s designed. Stack foundation is a concrete structure used for example in Wärtsilä power plants where it is used as a support for pipes. In this work I have considered different loads and powers which saddle this structure. I also have considered about the environment and surrounding conditions. The example structure is drawn with AutoCad, the structural model is made with Staad Pro and the calculation base is made with Excel.

The designer has the basic information about the project and the guide gives directional answers how to continue with the planning.

1.2 Contents and goals of the work

The problem has been that there hasn’t been any specific handbook or guide to design a stack structure. Structures have been designed by old information from other calculations and projects. The guide is to be used in daily designing and to be as a support for handmade calculations. The designer can check the right measures for the foundation with the Excel base and re-design the model if necessary.

This guide is to be directional and as a support for actual work. The Ecxel- base is to be used side by side with handmade calculations and to check the answers. The calculation -base could also be used with similar structures.

1.3 Company

Citec Engineering was founded in 1984 by Rune Westergård and Rolf Berg within the field of mechanical engineering. (Citec Insider 2008)

During the first few years the company was a small engineering firm. In the early 1990's a more rapid expansion phase began simultaneously as new lines of business emerged: environmental consultancy and technical documentation. These lines of business became two separate corporations in 1993 (Citec Environmental) and 2001 (Citec Information). In 2008 Citec Environmental became part of Citec Engineering Oy Ab. Citec consists two sister companies that are legally independent but do share some administration and support functions. The Citec companies are Citec Information Oy Ab and Citec Engineering Oy Ab. (Citec Insider 2008)

Both companies together employ close to 1000 people and the turnover in 2007 was 47 million euros. The Citec companies have a different owner structure. The founders and other key persons in the company are owners. Additionally, the insurance company Tapiola owns 14% of Citec Information. All three companies work under the same marketing brand - Citec. (Citec Insider 2008)

Citec Engineering provides advanced multi-discipline solutions and consultant services for industry. We create customer interest by development initiatives and we gain customer trust by outstanding services. (Citec Insider 2008)

1.4 Products

Citec Engineering offers multi-engineering design and consulting services for industry. Citec has expertise in mechanical engineering, automation and electricity, civil and structural, process and environment, product development and modularization, water management, project management and a variety of specific technical services. Engineering department is responsible for resourcing, subcontracting and competence development based on the requirements from the Business Areas. (Citec Insider 2008)

2 STAAD PRO

2.1 Introduction

STAAD.Pro is an analysis and design software package for structural engineering. This manual is intended to guide users who are new to this software as well as experienced users who want specific information on the basics of using the program.

Part I of this manual describes the following:

- Hardware Requirements
- Installation & licensing
- Running STAAD.Pro
- Running Sectionwizard
- Running Mesher

Part II of this manual contains tutorials on using STAAD.Pro. The tutorials guide a user through the processes of:

- Creating a structural model. This consists of generating the structural geometry, specifying a member property, material constants, loads, analysis and design specifications, etc.
- Visualization and verification of the model geometry.
- Running the STAAD analysis engine to perform analysis and design.
- Verification of results - graphically and numerically.
- Report generation and printing.
  (http://www.scribd.com)

2.2 System requirements

The following requirements are suggested minimums. Systems with increased capacity provide enhanced performance.

- PC with Intel-Pentium or equivalent.
- Graphics card and monitor with 1280x1024 resolution, 256 color display (16 bit high color recommended).
- System memory: Minimum of 512 MB, 1 GB better, 2 GB recommended.
- Windows NT 4.0 or higher operating system. Windows 95, Windows 98 & Windows Me are no longer supported. The program works best onWindows 2000, XP, Vista, or Windows 7 operating systems.
- Sufficient free space on the hard disk to hold the program and data files. The disk space requirement will vary depending on the modules you are installing. A typical minimum is 500MB free space.
- A multi-media ready system with sound card and speakers is needed to run the tutorial movies and slide shows.

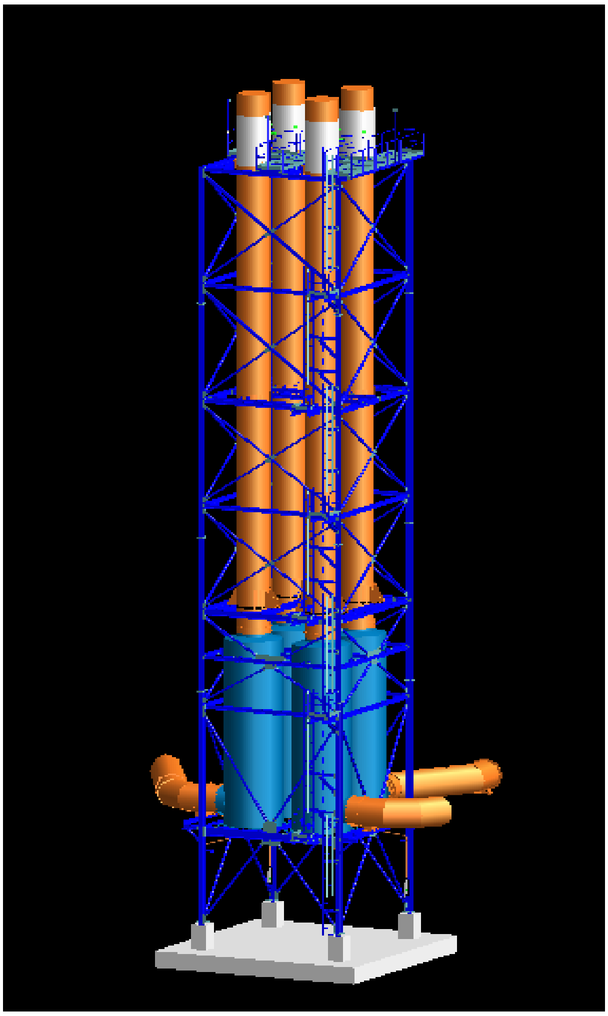
Additional RAM, disk space, and video memory will enhance the performance of STAAD.Pro.

(http://www.scribd.com)

3 DESIGN

3.1 Input data

This structure has been designed according to Eurocode standards. In my thesis, this stack is approximately 40 meters high structure supporting the exhaust pipes of four Wärtsilä W18V46 engines of a power plant. The stack foundation is always under the ground and has four shallow piles on top of it to hold the stack. That means that the white part that is shown in the picture is under the ground.



Kuva 1 (Citec insider)

3.2 Site

The preliminary investigations should be planned in such a way that adequate data are obtained. Assess the overall stability and general suitability of the site also in comparison with alternative sites. Defining the suitable positioning of the structure and evaluate the possible effects of the proposed works on surroundings, such as neighboring buildings, structures and sites. Consider the possible foundation methods and any ground improvements. Plan the design and control investigations, including identification of the extent of ground which may have significant influence on the behavior of the structure. (Eurocode 7, EN 1997-2)

A preliminary ground investigation should supply estimates of soil data concerning the type of soil or rock and their stratification. The groundwater table or pore pressure profile should be done if relevant. The preliminary strength and deformation properties for soil and rock must be investigated. The potential occurrence of contaminated ground or groundwater that might be hazardous to the durability of construction material has to be considered. (Eurocode 7, EN 1997-2)

The example environment surrounding the stack structure is shown in Figure 2.

Kuva 2 (Citec insider)

3.3 Environment

In geotechnical design, the detailed specifications of design situations should include the actions, their combinations and load cases. The general suitability of the ground on which the structure is located, must respect to overall stability and ground movements. The disposition and classification of the various zones of soil, rock and elements of construction, are involved in any calculation model. Ground and ground-water conditions must be investigated properly likewise regional seismicity. Influences of the environment such as hydrology, surface water, subsidence, seasonal changes of temperature and moisture has to be processed separately. (Eurocode 7, EN 1997-2)

If needed, the designer gets the report of the environment from the client. The report should include all necessary information of the site.

4 SOIL

4.1 Ground conditions

It should be considered that knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations. The report of the environment includes also information of the ground conditions.

Ground investigations shall provide a description of ground conditions relevant to the proposed works and establish a basis for the assessment of the geotechnical parameters relevant for all construction stages. Investigations should also consist of field investigations, laboratory testing, additional desk studies and controlling and monitoring, where appropriate. (Eurocode 7, EN 1997-2)

Special attention should be paid to sites that have been previously used, where disturbance of the natural ground conditions may have taken place. An appropriate quality assurance system shall be in place in the laboratory, in the field and in the engineering office, and quality control shall be exercised competently in all phases of the investigations and their evaluation. (Eurocode 7, EN 1997-2)

4.2 Shrinkage and creep

Shrinkage and creep are time-dependent properties of concrete. Their effects should generally be taken into account for the verification of serviceability limit states. The effects of shrinkage and creep should be considered at ultimate limit states only where their effects are significant. In other cases these effects need not to be considered for the ultimate limit states, provided that ductility and rotation capacity of the elements are sufficient. If the concrete is exposed to air, the larger part of the free water evaporates and the rate and completeness of drying depending on ambient temperature and humidity conditions. As the concrete dries, it shrinks in volume, probably due to the capillary tension that develops in the water remaining in the concrete. (Design of concrete structures, Arthur H. Nilson)

Creep and shrinkage of the concrete depend on the ambient humidity, the dimensions of the element and the composition of the concrete. Creep is also influenced by the maturity of the concrete when the load is first applied and depends on the duration and magnitude of the loading. (EN 1992-1-1:2004 (E))

4.3 Thermal effects

Like most other materials, concrete expands with increasing temperature and contracts with decreasing temperature. The effects of such volume changes are similar to those caused by shrinkage, which means that the temperature can lead to objectionable cracking, particularly when superimposed on shrinkage. Thermal effects should be taken into account when checking serviceability limit states. They should be considered for ultimate limit states only where they are significant. In other cases they need not to be considered, provided that the ductility and rotation capacity of the elements are sufficient. (Eurocode 2, EN 1992-1-1)

4.4 Groundwater investigations

If relevant, field investigations in the design phase should comprise drilling and/or excavations for sampling, groundwater measurements and the field tests. The various types of field investigation are field testing, soil and rock sampling, groundwater measurements, geophysical investigations and other large scale tests. (Eurocode 7, EN 1997-2)

The locations of investigation points and the depths of the investigations should be selected on the basis of the preliminary investigations as a function of the geological conditions, the dimensions of the structure and the engineering problems involved. (Eurocode 7, EN 1997-2)

The investigation points should be arranged in such a pattern that the stratification can be assessed across the site. The points for a building or structure should be placed at critical points relative to the shape, structural behavior and expected load distribution. For linear structures, investigation points should be arranged at adequate offsets to the center line, depending on the overall width of the structure, such as an embankment footprint or a cutting. (Eurocode 7, EN 1997-2)

4.5 Drainage

The objective of the drainage is a controlled removal of the rainwater’s from the site. The location and level of conduit channels and routes have to be taken into account when designing the drainage.

Designing the drainage in the site starts with the choice of the dimensioning rain. If information of local precipitation is not found the following dimensioning rain amounts should be used. In tropical areas is 150mm per hour and in other areas 105mm per hour. The duration of dimensioning rain is 10 minutes.

Trenches are used for drainage the border of the site and within the site, if the depth is less than one meter. Trenches have usually a shape of trapezoid or triangle and the normal inclination of the cheek of the trench is 1:1.5.

The maximum depth of the trench is 1.0 meter and the maximum width is about 3 meters. (Wärtsilä design handbook)

5 LOADS

5.1 Basics

Structural loads are forces applied to a component of a structure or to the structure as a unit. In structural design, assumed loads are specified in national and local design codes for types of structures, geographic locations, and usage. In addition to the load magnitude, its frequency of occurrence, distribution, and nature (static or dynamic) are important factors in design. Loads cause stresses, deformations and displacements in structures. Assessment of their effects is carried out by the methods of structural analysis. Excess load or overloading may cause structural failure, and hence such possibility should be either considered in the design or strictly controlled. (Design of reinforced concrete. McCormac, Jack C.)

In this case loads are:

- dead loads: structure weight, pipe weight, steel structure weight
- live loads: wind load, snow and ice loads, rain load and impact loads (for example earthquake)

5.2 Dead loads

The dead load is the weight of the structure acting with gravity on the foundations below. Snow load is the weight of the dead load and the imposed load but also the weight of the snow on top which could cause damage to the roof. Dead loads are those that are constant in magnitude and fixed in location throughout the lifetime of the structure. Usually the major part of the dead load is the weight of the structure itself. This can be calculated with good accuracy from the design configuration, dimensions of the structure and density of the material. (Design of the concrete structures, Arthur H. Nilson)

5.3 Live loads

Live loads, or imposed loads, are temporary, of short duration, or moving. Examples include snow, wind, earthquake, traffic, movements, water pressures in tanks, and occupancy loads.

Snow is a variable load, which may cover an entire roof or only part of it. There may be drifts against walls or buildup in valleys of between parapets. Snow may slide off one roof to a lower one. The wind may blow it off on side of a sloping roof, or the snow may crust over and remain in position even during very heavy winds. Impact loads are caused by the vibration of moving or movable loads. These loads are equal to the difference between the magnitude of the loads had they been dead loads. (Design of reinforced concrete. McCormac, Jack C.)

The magnitudes of wind loads vary with geographical locations, heights above ground, types of terrain surrounding the buildings including other nearby structures, and other factors. Wind pressures are usually assumed to be uniformly applied to the windward surfaces of buildings and are assumed to be capable of coming from any direction. Wind forces act as pressures on vertical windward surfaces, and suction on flat surfaces and on leeward vertical and sloping surfaces. (Design of reinforced concrete. McCormac, Jack C.)

These are loads that display significant dynamic effects. Examples include impact loads, waves, wind gusts and strong earthquakes. Because of the complexity of analysis, dynamic loads are normally treated using statically equivalent loads for routine design of common structures. Dynamic loads are also caused by a force other than gravity.

6 PRELIMINARY VALUES

6.1 Preliminary dimensions

A structure should be designed and executed in such a way that it will sustain all actions and influences likely to occur during execution and use, and remain fit for the use for which it is required. A structure must have structural resistance, serviceability, and durability.
The designer gets the preliminary dimensions for the structure from steel structure designer. Steel structure designer evaluates the dimensions based on the steel part of the stack structure. The designer may use either STAAD Pro or Robot Millennium calculation programs. The results are able to insert to calculation base after checking the direction of the axes in the program.

6.2 Planning and execution of measurements

$fck = 25N/mm^2$ $\gamma_c = 1.5$

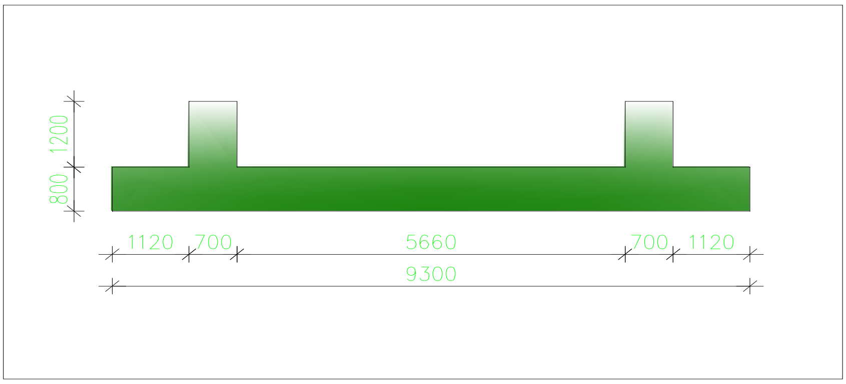
$fcd = 0.85 \times fck/\gamma_c$ $fcd = 0.85 \times 25N/mm^2 / 1.5 = 14.2N/mm$

Slab geometry:

$b = 9300mm$
$h = 800mm$
$fctm = 2.21N/mm^2$
$fyk = 400N/mm^2$
$cb = 75mm$
$dbt = 715mm$
$dtt = 755mm$

Dimensions are shown in Figure 4 which is a section of a stack foundation.

The measurements are preliminary and are estimates of a right kind of stack.



Kuva 3

6.3 Design tools

I made the structural model with Staad Pro 2007 system. Staad Pro is a comprehensive and integrated element analysis and design program, including a state-of-the-art user interface, visualization tools, and international design codes. Capable of analyzing any structure exposed to static loading, a dynamic response, soil-structure interaction, wind, earthquake, and moving loads.

In Staad Pro model I used an example case from Citec Engineering. I used an old Wärtsilä power plant stack and made a Staad model of that. I calculated the powers and loads by hand also to see if the answers match. From the Staad model I took the support reactions report and loads to Excel base. (Attachment 1)

The designer inserts support reactions from STAAD report. Designer must choose the greatest load case or cases from the report, so that the calculation base defines the ultimate case. In calculation base is possible to choose if there is ground filling weight or not. Designer must insert the height, the measures of the chosen structure and find the right load cases from the report.

The calculation base announces if the foundation is executable and in which Zone it is. (See Figure 7.)

7 SUMMARY

This thesis is a directional dimensional example for designing a stack foundation. The purpose was to create a handbook which gives preliminary information of what is needed when a designer is going in this part of the project. The basic information comes from the site and the purchaser. Then the designer has a guide for preliminary measuring and the example calculations for the case.

The Excel calculation sheet is to check if the foundation is approximately right or if it has to be redesigned. The loads in STAAD Pro may change depending on the conditions in the site. Eurocode standard is an important tool using with this handbook. They don’t use Eurocode elsewhere than in Europe, but the main tool in this thesis is the Excel sheet, which is completely same mathematics as all over the world.

The sheet is independent tool, which can be used also with other structural programs and also as an individual help in designing process.

8 RESOURCES

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9 ATTACHMENTS

ATTACMENT 1 STAAD Pro model

ATTACHMENT 2 Support reactions report

ATTACHMENT 3 Excel calculation base