113-th European Study Group with Industry (ESGI' 113)

September 14-18,2015
Sofia, Bulgaria

PROBLEMS & FINAL REPORTS

FASTUMPRINT
2015

Organizers:

Institute of Information and Communication Technologies, BAS,

Faculty of Mathematics and Informatics,
Sofia University "St. Kl. Ohridski" and

Institute of Mathematics and Informatics, BAS

in cooperation with

European Consortium for Mathematics in Industry

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Preface

The 113th European Study Group with Industry (ESGI'113) was held in Sofia, Bulgaria, September 14–18, 2015. It was organized by the Institute of Information and Communication Technologies, Bulgarian Academy of Sciences (IICT-BAS), the Faculty of Mathematics and Informatics, Sofia University "St. Kliment Ohridski" (FMI–SU) and the Institute of Mathematics and Informatics, BAS (IMI–BAS) in cooperation with the European Consortium for Mathematics in Industry (ECMI). The ESGI'113 was the third Study Group in Bulgaria, after the very successful ESGI'104, September 23–27, 2014 and ESGI'95, September 23–27, 2013.

ESGI'113 was financially supported by the project Advanced Computing for Innovation (AComIn) funded by FP7 Capacity Programme, Research Potential of Convergence Regions under the grant agreement 316087/2012, and by the Sofia University grant N075/2015. The event was also sponsored by the companies that posed problems for solving, as well as by the project "Supercomputing Expertise for Small and Medium Enterprise Network", (SESAME-NET), funded by the EU's Horizon 2020 research and innovation programme under grant agreement 654416.

ESGI113 was hosted by the Institute of Information and Communication Technologies, BAS, and by the Institute of Mathematics and Informatics, BAS. The two institutions have provided excellent conditions for work.

Study Groups with Industry are an internationally recognized method of technology transfer between academia and industry. These one-week long workshops provide an opportunity for engineers and industrial developers to work alongside academic mathematicians, students, and young professional mathematicians on problems of direct practical relevance.

The Organizing Committee selected six problems to work on:

1. *Spline intersection improvement*, Chaos Group Ltd.;
2. *Development of mathematical algorithm for direct ascription of missing values in survey research data*, GemSeek;
3. *Optimal Cutting Problem*, STOBET Ltd.;
4. *The 2D/3D Best-Fit Problem*, EngView Systems Sofia;
5. *Analytical solution for consolidation of a soil layer with finite thickness under cyclic mechanical loading*, GEO|RUHR, Germany;

6. *Cyber Intelligence Decision Support in the Era of Big Data*, STEMO Ltd..

Five of the companies are Bulgarian. The founders of the company GEO|RUHR, Germany have had a long time collaboration with the Institute of Mechanics, BAS.

The participants from Bulgaria (42) and from abroad (2) were divided into six groups, each group working as a team on one problem. The Bulgarian participants were from various Academic institutions: FMI-SU; IMI-BAS; IICT-BAS; Plovdiv University; Veliko Tarnovo University; Technical University of Sofia, University of Rousse. The participants from the University of Novi Sad, Serbia and the Ruhr-University Bochum, Germany, made valuable contributions to the work on the problems.

A separate event, Preparatory Modelling Week, was organized this year by FMI, Sofia University, for senior Bachelor students, Master and Doctoral students. It was designed to run back-to-back (07–11.09) with ESGI'113, providing problem-solving experience and a warm-up for the work in the Study Group. All Modelling week attendees were expected to participate at the study group and this really happened. Twelve of the ESGI participants were students: four Doctoral, four Master and four Bachelor students. The Master students were from the FMI Master programs on Computational mathematics and mathematical modelling and Mathematical modelling in economics, evaluated as ECMI Master Programs in Industrial Mathematics, branch Techno-mathematics and Econo-mathematics respectively.

On the last day of the workshop each group made presentation on the progress in solving their problem and on recommended approaches for their further treatment (including generalization, improvements and implementations. The presentations were the basis of the final report which each group has prepared. These were assembled in this booklet to form the Study Group Final Report and to provide a formal record for the work for both the industrial and academic participants.

The description of the problems, the last day presentations and the final reports of each working group are posted on the website of the ESGI'113:
http://parallel.bas.bg/ESGI113

As at ESGI'95 and ESGI'104, certificates for participation and for valuable contribution were given to the participants.

The next Bulgarian Study Group is planned to be held in Sofia in the period July 24-28, 2016, immediately after the ECMI Modelling Week'2016, July 17-21.

List of participants

Ana Avdzhieva (Sofia University, FMI)
Assen Tchorbadjieff (IMI, BAS)
Branko Markovic (University of Novi Sad, Serbia)
Cihan Menseidov (University of Ruse)
Detelina Kirova (IMI, BAS)
Dimitar Fidanov (Plovdiv University, FMI)
Dimo Dimov (IICT, BAS)
Doychin Boyadzhiev (Plovdiv University, FMI)
Dragomir Aleksov (Sofia University, FMI)
Eliza Ilieva (Sofia University, FMI)
Galina Lyutskanova (Sofia University, FMI)
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Tomas Barciada (Ruhr-University Bochum, Germany)
Tsvetomir Tsachev (IMI, BAS)
Vasil Kolev (IICT, BAS)
Velislav Bodurov (Sofia University, FMI)
Vencislav Pirinski (TU, Sofia / IICT, BAS)
Venelin Valkov (Plovdiv University, FMI)
Veska Noncheva (Plovdiv University, FMI)
Zlatogor Minchev (IICT, BAS / IMI, BAS)

PROBLEMS

Problem 1. Spline Intersection Improvement

Chaos Group Ltd., www.chaosgroup.com

Yordan Mandzhunkov, yordan.madzhunkov@chaosgroup.com

Company's overview. Chaos Group creates physically-based rendering and simulation software for artists and designers. Founded in 1997, Chaos Group is a Bulgarian company that has devoted the last 18 years to helping artists advance the speed and quality of one of their most important tools. Today, Chaos Groups photorealistic rendering software, V-Ray®, has become the rendering engine of choice for many high-profile companies and innovators in the design and visual effects industries.

A task that we typically perform is intersection of spline curves with a ray. We already have developed several models how to intersect such primitives with rays. However, we are looking for a way to improve our current model in terms of accuracy, without sacrificing too much computation speed.

Problem. We model spline curve primitives with 4 control points in 3D space – p_0; p_1; p_2; p_3. Each control point has it's own width of the curve – w_0; w_1; w_2; w_3. Spline curve center as function of curve's evolution parameter $u \in [0, 1]$ is described with

$$\vec{p}(u) = \vec{p_3}u^3 + 3\vec{p_2}u^2(1-u) + 3\vec{p_1}u(1-u)^2 + \vec{p_0}(1-u)^3. \tag{1}$$

The width of the primitive as function of the same evolution parameter is given by:

$$w(u) = w_3u^3 + 3w_2u^2(1-u) + 3w_1u(1-u)^2 + w_0(1-u)^3. \tag{2}$$

The point that lies on the surface of the primitive has to satisfy the system:

$$\begin{aligned} |\vec{s}(u) - \vec{p}(u)|^2 &= w(u)^2 \\ (\vec{s}(u) - \vec{p}(u)) \cdot \frac{d\vec{p}(u)}{du} &= 0. \end{aligned} \tag{3}$$

For a given ray

$$\vec{r}(t) = \vec{o} + t\vec{d} \tag{4}$$

find $t > 0$ and $u \in [0, 1]$ such that

$$\vec{r}(t) = \vec{s}(u). \tag{5}$$

In case of multiple solutions, we are only interested in the one that has minimum t. We are interested in numerical method that is programmable in c++ and can find accurate solution at the lowest computational cost.

Motivation. The spline curve primitives we described above are widely used for hair in V-Ray. In scene that has one human like character there are typically several million hair strands. Each hair can be composed by many spline primitives. Therefore we need to be able to intersect hair as fast as possible. We have already implemented acceleration data structures as bounding volume hierarchy (BVH) and k-d tree to accelerate intersection. We will use the spline intersection method that you provide, as last phase of the intersection process – after the ray already intersected the bounding box of the spline. We also included a rendered image using our current intersection model:

Problem 2. Development of Mathematical Algorithm for Direct Ascription of Missing Values in Survey Research Data

GemSeek, www.gemseek.com

Martin Dimov, martin.dimov@gemseek.com

Company's overview. GemSeek is a market intelligence and consulting company. It helps business leaders with decision support analytics that have a direct impact on bottom line and competition. Company's services are organized around Data science and predictive analytics, Market & Industry Intelligence, Customer Insight & Brand Analytics, Advanced Visualization Solutions and Competitive Intelligence.

Definition of the problem. One of Gemseek's core activities is developing and implementing marketing survey research studies among different target groups both on local market and across the world. The results serve as basic foundation for further analysis on customer perceptions, behavior and brand affiliation. Hence, the necessity of complete datasets is a prerequisite for sustainable analyses, robust analytics and unbiased interpretation of results. One of the biggest challenges for company was dealing with "blank spots" in the data i.e. places where respondents refrain from providing correct answering due to various reasons. Some of these include difficulty to find correct answer, too long questionnaires, unwillingness to disclose sensitive personal information (income, age etc.), too many options to choose from etc.

Since most statistical analysis methods assume the absence of missing data and are only able to include observations in which every variable is measured, GemSeek is in need of a robust mathematical approach that could impute incomplete data sets so that analyses which require complete observations can appropriately use all the information present in a dataset without missingness. In this case the level bias and incorrect uncertainty estimates will be avoided.

Task description. In 2014 the company has performed a study among 600 customers of the biggest supermarket chains in Bulgaria. The methodology used

random sampling procedure among population in Bulgaria's top 8 cities. The variables were measured with different type of scales: nominal, ordinal and continues in some of the cases. As a result the final dataset contained a large number of missing cases and "no answers" across variables ranging from 5% to around 50% of all respondents interviewed.

Since all methods for stimulating response rate were exhausted GemSeek is looking for a **computational algorithm** that could use the information from already completed cases and recursively assign values to missing data in every variable controlling for the type of scale and distribution of "real" values. For this exercise we assume that all missing values are of type: Missing At Random (MAR).

Expected results

- Brainstorm on various methods of solving the task;
- Presentation of different algorithms, stating pros and cons for each one;
- Used variables, predictors, distance measures, parameter estimates etc.;
- Suggestions of appropriate software and tools, complete scripts and developer codes for completing the task;
- Discussion of the results with bigger audience.

Assessment criteria. All suggestions for algorithms will be closely reviewed and assessed by Gemseek team. Following criteria will be used when choosing the most effective method:

- Accuracy – measured as percentage of accurately imputed cases vs.real cases;
- ROC curves and Confusion matrices – as a way of graphical visualization of accuracy;
- AIC and BIC – as a method for comparing different methods and their efficiency;
- Statistical significance and hypothesis testing – as non-parametric estimation of results.

Materials provided

- Incomplete data set of survey results in CSV format which could be used for imputation methods and comparing the results;
- Complete questionnaire containing names and labels of all variables in the dataset.

Other information and resources and consultations will be readily available from Gemseek team on request.

Problem 3. Optimal Cutting Problem

STOBET Ltd., www.stobet.com

eng. Georgi Evtimov

Company's overview. STOBET is a structural engineering bureau that was set up in 2003 in the city of Sofia by Georgi Evtimov Evtimov. Since its very start the bureau has been dealing with structural design of buildings and facilities. The bureau designs a variety of structures: reinforced concrete, metal, wood and – recently quite often – combined types of structures: steel and reinforced concrete, metal and wood. Combined structures provide very flexible and cheap solutions.

Definition of the problem. Making the project by part "Constructions" contains many drawings. Plotting the project – drawing by drawing – is a laborious work, which is repeated for each printing. The number of drawings can reach 700-800 numbers in one project. For this reason it is necessary to arrange all "small" drawings in the "big" paper in the plotter with a minimum wastage of paper.

Task for optimization

Task 1. We have a large piece of paper $X = 1000$ mm, $Y = 15000$ mm. In this paper many small rectangles (drawings) with dimensions (a_i, b_i), $i = 1, \ldots, n$ should be arranged (see Fig. 1). The goal is to arrange the rectangles in such a way that they fill the entire width of the paper (1000 mm) and use the least possible length of the sheet (i.e. the rectangle that contains all the small drawings has the least possible length). In the process of arranging the "small" rectangles (drawings) can be rotated at any angle (0, 90, or any).

Task 2 (Linear cutting). We have in stock N pieces of rods with section X and length L meters. After the design is given, we need to obtain M_j rods with section X and lengths P_j meters, $j = 1, \ldots, m$. The question is how to combine the rods available so that the minimum possible spolage is obtained.

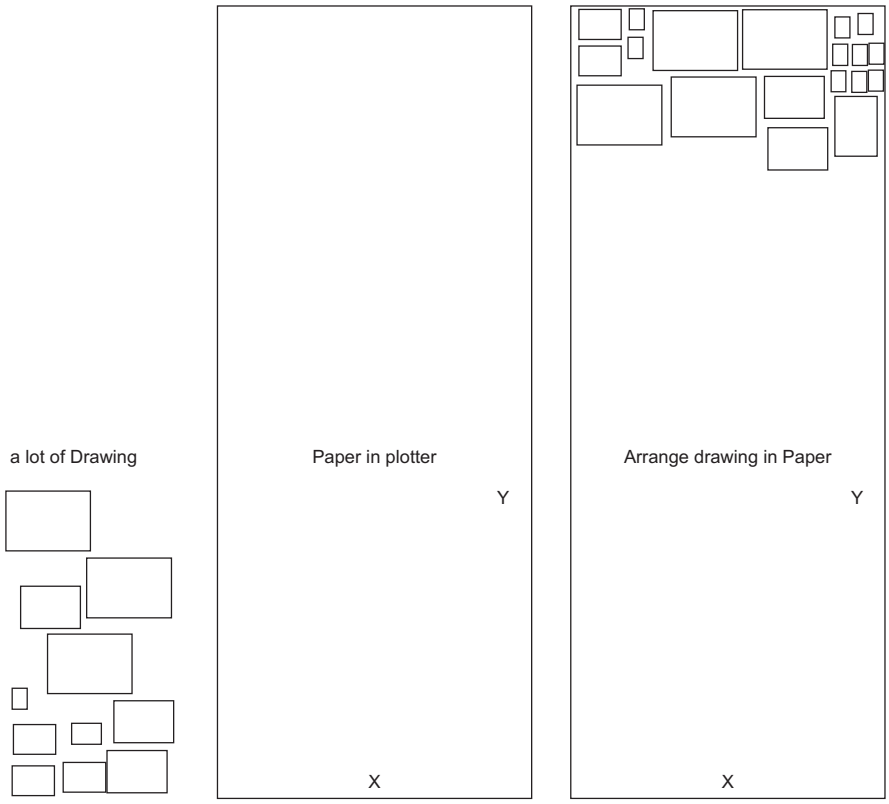


Fig. 1

Example

We have in stock $N = 12$ pcs with section $X =$ IPE200 and length $L = 12000$ mm.

After the design we have to obtain $M = M_1 + M_2$ profiles with section $X =$ IPE200:

1. $M_1 = 18$ pcs with length $P_1 = 7350$ mm,
2. $M_2 = 53$ pcs with length $P_2 = 121$ mm.

The width of cut is 5 mm.

Problem 4. The 2D/3D Best-Fit Problem

EngView Systems Sofia (A Sirma Group Company), www.engview.com

eng. Peter Konyarov, Peter.Koniarov@sirma.bg

Company's overview. Sirma Group Holding JSC is one of the largest software groups in Southeast Europe, with a proven track record since 1992. The group employs more than 300 experienced software professionals who have implemented hundreds of successful projects worldwide.

Sirma has gained substantial expertise in some of the most innovative areas of ICT: semantic technologies, mobile applications, ERP (Enterprise Resource Planning), BI (Business Intelligence), financial, banking and payment services, e-government and others. Our successful projects laid the foundation of the long-term customer relationships. Following its visionary mission, our company has focused on the creation of new knowledge enterprises. A few of Sima subsidiaries are among the world leaders in their verticals.

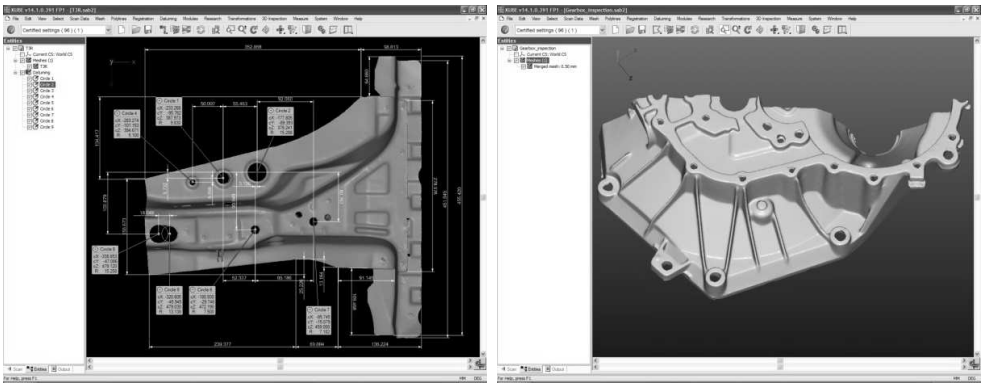
The Group traditionally launches innovative businesses; it founded its own business incubator for technology startups a few years ago. Our companies have won many international and national awards. For instance, Sirma Solutions JSC was awarded the Forbes Business Awards 2012 in "Business Development" category; Ontotext won the Innovation Enterprise Award 2014 in the category "Innovation Visionary", the prize of the 3rd NewsHack2014 contest on the BBC. Sirma Mobile JSC was honoured with the prestigious prize for mobile security SIMagine 2011. Sirma Business Consulting JSC was distinguished twice for the Best ICT employer for 2014 and 2012. EngView Systems Jsc, our subsidiary company for CAD/CAM software, was awarded with the European Information Technology Prize.

Problem description. In computer systems, the best-fit problem can be described as a search for the best transformation matrix to transform input measured points from their coordinate system into a CAD model coordinate system using a criteria function for optimization. For example, if the criterion is Minimum Sum of Deviations, we search for a transformation matrix M that minimizes the sum of all distances from an matrix-transformed measure points to a CAD model.

The formula that describes this process is as follows:
$\sum_{i=1}^{n} dist(Pi.M, CADsurface) \to 0$, where n is the number of points and $Pi.M$ is the matrix-transformed measured input point.

The case. The standard case where the problem takes place is quality control of part production. The process is as follows:

1. Engineers create a part as a CAD model in the coordinate system A (Pic 1).



Pic 1. The CAD model is in the coordinate system A

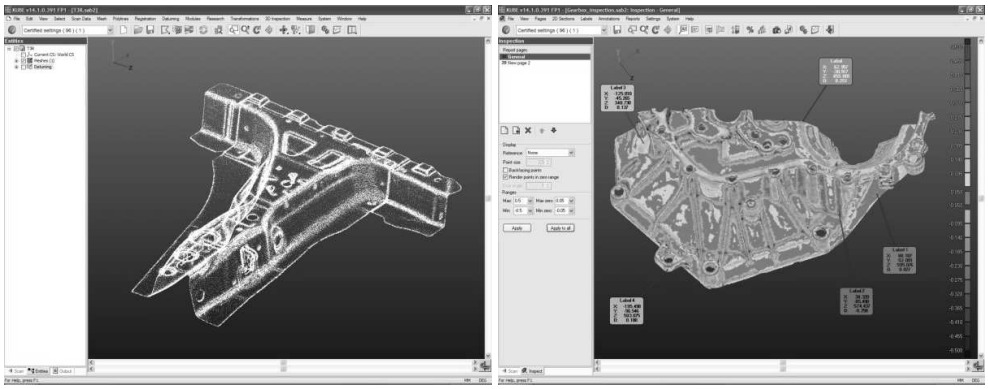
2. The part is produced and is measured as a real-point cloud in the coordinate system B (Pic 2).

Pic 2. The physical part is scanned in the coordinate system B as a points cloud or as a triangular mesh

3. The best-fit matrix allows the direct comparison of the produced part surface relative to the wanted design. After the produced part has been compared with the designer project, it either:

– Passes quality inspection and becomes part of a product, or

– Does not pass quality control, and as a result is discarded.



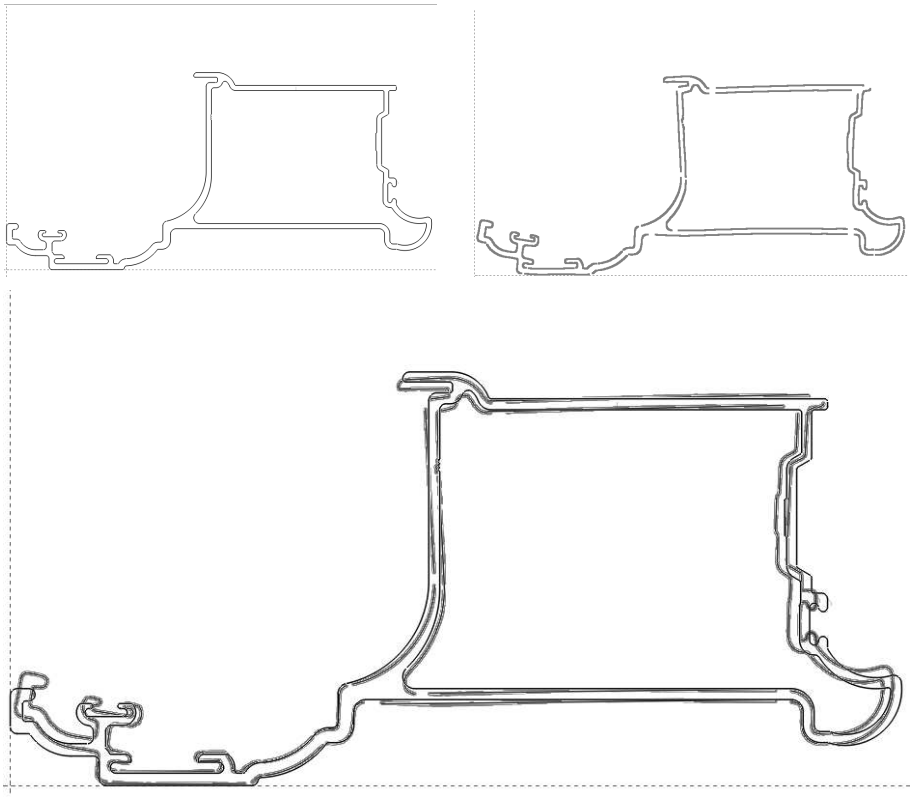
Pic 3. We search for the best transformation that will transform points from coordinate system B to coordinate system A

The solution. The best algorithmic solution should include the following features:

1. Partial fit (only part of the object is scanned).
2. Different parts (these could also be measure points) can have their own individual weights.
3. Only some of the three rotations and three translations can be applicable.
4. The algorithm can be applied on 2D or 3D data.
5. Preliminary assessment can be made if there are points that constitute noise. If such points are detected, they should be filtered out.
6. In the ideal case, the algorithm's input data – these are the data in the two coordinate systems – can appear as points, as a mesh, or as a CAD model.
7. Optimization can take place by different optimization criteria: least squares, minimum sum of deviations, mini-max, uniform deviations, minimum standard deviation, tolerance envelope, tolerance envelope mini-max.
8. The fit process should be able to accept also partially deformed parts. Even if there are discrepancies between the CAD model and the input data, the algorithm must be able to process them.
9. The computation needs to be fast and efficient.

10. An option could exist for multi-core, parallel computation.

2D example:



Problem 5. Analytical solution for consolidation of a soil layer with finite thickness under cyclic mechanical loading

GEO|RUHR, Germany

Thomas Barciaga, Nina Müthing

1. Introduction. **GEO**|RUHR is a start-up in the field of geotechnical engineering. Among others we offer technology and scientific consultancy for the design of foundations of engineering structures. One of our business segments is the experimental and numerical subsoil analysis. In this framework we experimentally determine and evaluate soil parameters, which are necessary for the assessment of the subsoil behaviour as well as for the numerical modelling of foundation systems. Thereby, **GEO**|RUHR sets a focus on the analysis of engineering structures founded in soft soils under cyclic loading – e.g. foundation systems for on- and offshore wind turbines – as these systems are gaining increasing attention within the geotechnical community.

2. Objective. When founded on soft cohesive soils pore water dissipation and time evolution of settlements is a key issue in the analysis of relevant foundation systems, as these soils due to their low permeability show a retarded settlement behaviour. In order to do settlement and/or time prognoses for cyclically loaded foundation constructions an exact knowledge of the evolution of pore water pressure dissipation is important. For static loading this problem has been solved for many decades (see Terzaghi, 1923). However, for cyclic load applications as they can be found in the framework of on- and offshore foundation design this problem is not solved completely. By an experimental testing series **GEO**|RUHR is already able to do prognoses for the pore water dissipation behaviour. However, a comparison of the experimental data to an analytical solution of the consolidation equations is needed to validate the experimental testing results. This is requested as besides numerical methods, analytical solutions are strongly requested to verify the FEM results.

3. Mathematical Problem. An analytical solution for the consolidation process under cyclic loading exists in literature (see e.g. Barends, 2006, 2011).

However, this approach assumes non-realistic boundary conditions as a soil stratum with infinite depth or a layer of high thickness are treated.

Therefore, a solution for a finite soil stratum, or shallow depth (see Fig 1) characterised by the following parameters is to be derived:

H	thickness of the stratum
k	hydraulic permeability of the soil
K_s	bulk modulus
α	compressibility of the solid phase
β	compressibility of the fluid phase
n	porosity
γ	volumetric gravity of the fluid phase

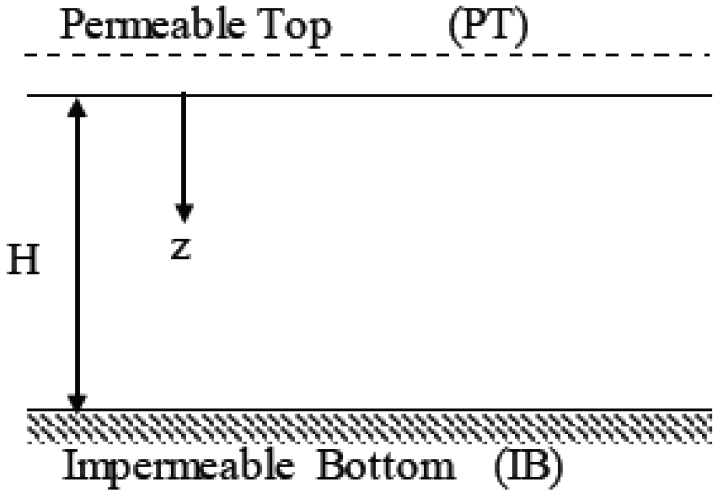


Figure 1. Soil stratum with given boundary conditions (permeable top, impermeable bottom – PTIB)

A vertical, cyclic load is applied to the top of the stratum, e.g. as haversine function of time or other:

$$L(t) = q \sin^2\left(\frac{\pi t}{d}\right) \quad \text{or} \quad L(t) = q \cos\left(\frac{\pi t}{d}\right),$$

where

$L(t)$	loading function
t	time
q	load amplitude
d	load period

The one-dimensional consolidation equation is given by

$$\frac{\partial u}{\partial t} = C_z \cdot \frac{\partial^2 u}{\partial z^2} + \frac{\alpha}{\alpha + n\beta} \cdot \frac{dL\,(t)}{dt}.$$

This equation describes the behaviour of the excess pore water pressure u with time and along the depth z. The consolidation coefficient C_z is given as:

$$C_z = \frac{k \cdot K_s}{\gamma(1 + \frac{n\beta}{K_s})}.$$

The boundary conditions may be given as follows

$$u\,(0,t) = 0, \quad \frac{\partial u}{\partial z}\,(H,t) = 0.$$

The initial condition is given as

$$u\,(z,0) = 0.$$

The task is to find an analytical solution to the above formulated boundary value problem. Next, based on the analytical solution to evaluate the following sub-tasks:

1. excess pore water pressure as a function of time and depth $u(z,t)$;
2. explicitly derive the phase shift ψ between excess pore water pressure $u(z,t)$ and the applied load with time (for a fixed depth) especially at the bottom ψ ($z = H$, $t \to \infty$), the phase shift or lag is a positive or negative delay of the excess pore water pressure as compared to the applied surface load that may vary with depth;
3. parameter analysis for the solution regarding permeability k as a function of relevant parameters (stratum height H, bulk modulus K_s, phase shift (see 2.), load amplitude q and loading period d).
4. parameter analysis for the phase shift ψ as a function of the fluid and solid phase compressibility and soil permeability.

Problem 6. Cyber Intelligence Decision Support in the Era of Big Data

STEMO Ltd., http://www.stemo.bg/

Georgi Dukov, Georgi_Dukov@stemo.bg

Company's overview. In 2016 STEMO Ltd. is going to celebrate 25 years anniversary with confirmed leading role in the field of information technologies. The company is providing a broad portfolio of IT products, solutions and services to our customers for building and enhancing the efficiency, productivity, security and reliability of their IT infrastructure.

Our versatile professional experience and expertise allow successful implementation of complex projects covering the complete life-cycle of each information system: **consultations, research, analysis, design, planning, implementation, training, operation, optimization, maintenance and upgrade.**

The company has 15 own commercial offices, service and retail centers, warehouses, a training center, equipped with modern information, technological and transport facilities. The branches of the company are situated in the largest cities of Bulgaria.

We employ 260 highly-qualified specialists: sales and technical consultants, service engineers, designers, programmers, economists, etc. with over 600 technical and sales certificates which cover the certification programs of leading world manufacturers.

Our main activities are encompassing almost all services, products and solutions in the field of information technologies, including:

- design, building and maintenance of complex information and communication systems
- delivery and installation of computer and office equipment, software and consumables
- specialized, professional IT services
- warranty and post-warranty support of computer equipment
- software development
- training and certification services

The quality management system of the company was implemented in 2000. It is certified in compliance with the requirements of international standards ISO 9001:2008 and AQAP 2110 NATO standards and covers all branches and activities of the company. The system ensures a high level of customer satisfaction, contributing to the stable development of the company and the fulfillment of corporate objectives. In 2010 the company certified the IT service and information security management according to ISO 20000 and ISO 27000 standards. In 2012 acquired certificates for environmental management ISO 14001 and health and safety management ISO 18001.

The company is a certified direct partner of leading world manufacturers: HP, Microsoft, Cisco Systems, SAP, Oracle, Fujitsu, DELL, Canon, Toshiba, Xerox, Epson, NetApp, VMware, Citrix, D-Link, EATON, APC, Samsung, LG, BenQ, 3M, ESET, Novell, Autodesk, AMP, R&M, Kerpen, Panduit, ITNI, OSPL, Crypto, Systematic, Imanami, Lieberman Softwar, NetSurity, Rola Security Solutions and others.

Our services help customers to achieve maximum return of investments in IT, enhancing the efficiency, productivity, security and reliability of their IT infrastructure. Our customers save time and resources and are able to concentrate on their main activity and priorities.

Over the years, the company financial results have shown a solid development and strengthened our role as an undisputed business leader in the IT market.

The biggest corporate organizations in Bulgaria, state and local administrations, industry and energy enterprises, telecommunication companies, banks, schools and medical centers, NGOs, thousands of SMEs and individuals are among our customers. We stand their success for our own priority.

Every year more than 10 000 organizations and individuals rely on our company as a correct, dedicated and reliable partner.

Problem description. Modern technologies in the digital society are constantly enlarging the cyber space scale, services and capabilities. This opens the necessity for proper understanding the behavior of todays' Internet users for assuring a more secure and predictable world. Understanding these evidently requires big data processing and relevant generalization for adequate decision support. STEMO Ltd. is a leading national security systems integrator working in this field since 2009 with multiple successful business partnerships.

Following our practical experience, one of the key problems in the field is to produce a useful aggregation and trends forecasting, in a suitable middleware, concerning the enormous direct and indirect Internet objects relations.

As these generate a number of hybrid threats for the users, critical infrastructure, e-services, AI evolution, M2M autonomous interaction and human-in-the-loop dynamic role, the resulting preventive measures, are quite demanding by means of computational resources and multiple decision makers adequate support.

Being rather comprehensive, the problem requires experts' data combination with big data statistical observations for practical achieving adequate cyber intelligence and countering cybercrimes and terrorist events.

Five key steps for solving the problem could be implemented:

1. Defining multiple cyber risks dynamic database.
2. Formulation of aggregation models, concerning data extraction and visualization.
3. Formulation of discrete optimization problems, taking into account the particular forecasting period, regarding expected critical events.
4. Choosing a software environment for solving the formulated problems.
5. Numerical experiments and discussion of results.