Ειδική Υπηρεσία Διαχείρισης και Εφαρμογής Δράσεων
στους τομείς Έρευνας, Τεχνολογικής Ανάπτυξης και Καινοτομίας

ΕΝΙΑΙΑ ΔΡΑΣΗ ΚΡΑΤΙΚΩΝ ΕΝΙΣΧΥΣΕΩΝ
ΕΡΕΥΝΑΣ, ΤΕΧΝΟΛΟΓΙΚΗΣ ΑΝΑΠΤΥΞΗΣ
& ΚΑΙΝΟΤΟΜΙΑΣ

ΕΡΕΥΝΩ – ΔΗΜΙΟΥΡΓΩ – ΚΑΙΝΟΤΟΜΩ

ΕΝΟΤΗΤΑ ΕΡΓΑΣΙΑΣ 1: ΔΙΕΡΕΥΝΗΣΗ ΑΛΓΟΡΙΘΜΩΝ ΒΕΛΤΙΣΤΟΠΟΙΗΣΗΣ

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ΑΝΤΑΓΩΝΙΣΤΙΚΟΤΗΤΑ
ΕΠΙΧΕΙΡΗΜΑΤΙΚΟΤΗΤΑ
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ΕΣΠΑ 2014-2020
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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

ADDING OPTIMIZATION CAPABILITIES TO EXISTING STRUCTURAL ANALYSIS SOFTWARE WITH OCP: A CASE STUDY

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ABSTRACT

Structural analysis programs usually compute a static model with cross sections given by the engineer or set to reasonable defaults. Any optimization of the structure with respect to a variable, for example weight/cost, is left to the experience of the engineer, usually because adding optimization capabilities to a structural analysis program is not trivial. Many optimization algorithms are available, each one with their own peculiarities, requirements, and performance. The variable to optimize is different for different projects such as material cost, construction cost, first eigen frequency and others. Adding to the complexity is the fact a static or dynamic analysis is computational expensive (time consuming) and thus the algorithms must be tuned to perform as few static analyses as possible.

Optimization Computing Platform (OCP) is software developed at ISAAR NTUA, which in combination with widely known structural analysis programs such as SAP2000 and ETABS, can optimize any structure with various algorithms, and with respect to various variables or a combination of them. Recently, OCP is actively developed to be program agnostic, so that it can be linked with any structural analysis program. The program gains painlessly mature and sophisticated optimization capabilities.

To test OCP, a truss static analysis program developed in house for educational and research purposes, was linked with OCP. This required relatively few modifications to the program, such as new functions to provide as callbacks to OCP, and new data input to the program such as the cross sections to optimize, the algorithm to use, etc. The latter is going to be input by a GUI provided by OCP in the near future. The combined program was used to compute a truss used in bridges. The optimization was performed with respect to weight (or cost). Two of the available OCP algorithms were used with similar results.

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ADDING OPTIMIZATION CAPABILITIES TO EXISTING STRUCTURAL ANALYSIS SOFTWARE WITH SOCP: A CASE STUDY

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Overview

SOCP: A general Optimization Computing Platform for Structural analysis software

2dTruss: static analysis and design program:
Steel bearing capacity
No optimization at all

Application of SOCP to 2dTruss:
enabling 2dTruss with optimization

Example

Conclusions

SOCP: A general Optimization Computing Platform for Structural analysis software

- SOCP: a library for enabling optimization in research and commercial structural analysis software

- Optimizes:
  - Size (sections)
  - Shape
  - Topology (experimental)

- Optimizes for (objective functions):
  - Weight/material cost
  - Compliance
  - First eigen frequency
  - Stiffness eccentricity, strength eccentricity
  - others

SOCP: A general Optimization Computing Platform for Structural analysis software

- Optimization algorithms:
  - PQN (quasi-Newton constrained nonlinear optimiz.)
  - GA (genetic algorithm)
  - TRL (Constrained optimization by linear approxim.)
  - many others

- Sections:
  - Circular, rectangular, Tee, channel, tube, I-shape and many others
  - Optimization of any or all section dimensions within limits

- Additional capabilities:
  - Computation of objective functions if the structural analysis program does not support them

2dTruss: static analysis and design program

- 2DTruss: Simple static analysis program (C++)

- Static analysis
  - Direct stiffness method
  - Displacements, reactions, bar axial forces

- Bearing capacity:
  - Steel
  - Rectangular sections
  - Bearing capacity of each bar

- Usage:
  - Educational
  - Change sections and run until bearing capacities are not exceeded
  - No optimization at all!

Application of SOCP to 2dTruss: enabling 2dTruss with optimization

- Interoperability:
  - Transfer model geometry to SOCP
  - Define design variables
  - Accommodate automatic design variables change
  - Accommodate static analysis
  - Get optimum results

- Implementation:
  - Library functions (set design variable, etc)
  - User call back functions (get coordinates, etc)

- Cross language interoperability (C++/C/C#/Fortran)
  - Usually pairs of call back functions:
  - One gets the total (e.g. total number of joints)
  - One gets the info (e.g. the coordinates of a joint)

Application of SOCP to 2dTruss: Library functions

Library functions:

- **`void setProjectPath_Cplus(const char *ppath)`**
  `void setLogPath_Cplus(const char *plogpath)`
  Sets the path of the project and log files

- **`void AddBounds_Cplus(int name1, int ndim, double minValues[], double maxValues[], double stepValues[], double values[])`**
  Defines one design variable with constraints

- **`void SetConvergence_Cplus(int iAlg1, int noCycles1, int maxFea1,double improvementPercentage1)`**
  Sets the convergence criteria

- **`RunSolver_Cplus(void)`**
  Begins the optimization process

Application of SOCP to 2dTruss: Library functions

Library functions which register call backs:

they take a single argument: the corresponding function (defined in the next slides)

- **void RegisterSetSectionDimensionsInt_Cplus(...);**
- **void RegisterMaterialPropertiesInt_Cplus(...)**
- **void RegisterMaterialPropertyInt_Cplus(...)**
- **void RegisterFramePropertiesInt_Cplus(...)**
- **void RegisterFramePropertyInt_Cplus(…)**
- **void RegisterPointObjectsInt_Cplus(...)**
- **void RegisterPointObjectInt_Cplus(...)**
- **void RegisterFrameObjectsInt_Cplus(...)**
- **void RegisterFrameObjectInt_Cplus(...)**
- **void RegisterPointElementsInt_Cplus(...)**
- **void RegisterPointElementInt_Cplus(...)**
- **void RegisterFrameElementsInt_Cplus(...)**
- **void RegisterFrameElementInt_Cplus(...)**
- **void RegisterLoadCombinationsInt_Cplus(...)**

Application of SOCP to 2dTruss: user defined call back functions

- **int RunAnalysis(double d[])**
  Runs the static analysis, sets d[] with the values of the computed objective functions and ratio of the maximum strength violation

- **int SetSectionPropertyInt(int PropName, const double SectionValue[], int sectionPropertyType)**
  Changes the dimensions of a single section (which may correspond to many elements)

- **int GetMaterialPropertiesInt(int& npropM)**
  int GetMaterialPropertyInt(int ID[], int MatType[])
  Gets material properties (eg concrete or steel); it may correspond to many elements

- **int GetFramePropertiesInt(int &npropF)**
  static int GetFrameProperty(int IDname1, int& mat, double& secArea, double secDim[], int& type)
  Gets the initial dimensions and constrains of a single section (which may correspond to many elements)

Application of SOCP to 2dTruss: user defined call back functions

- **`int GetPointObjects(int& number)`**
  `int GetPointObject(int IDname1, double xyz[])`
  Gets point coordinates

- **`int GetFrameObjects(int& number)`**
- **`int GetFrameObject(int IDname1, int& IdpropName, int joints[])`**
  Gets element definitions (element joints and properties)

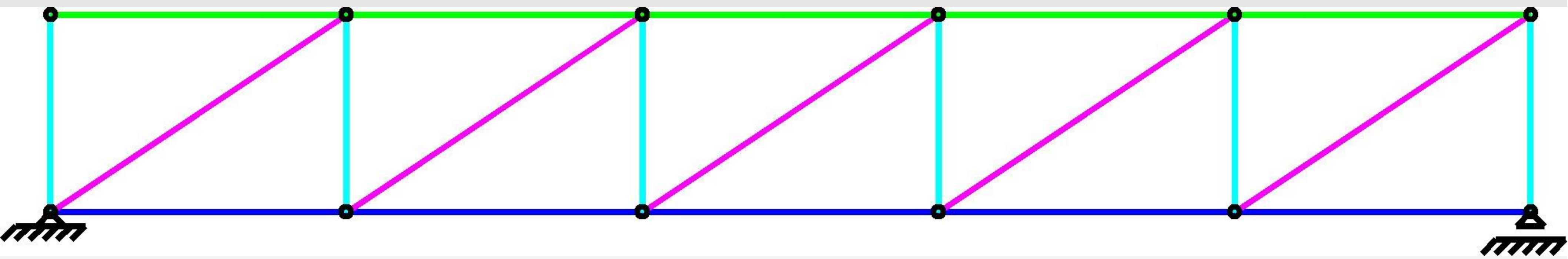
- **`int GetLoadCombinations(int& nComb)`**
  Gets the number of load combinations

- All functions return nonzero values in case of error

Example 1: Size optimization of bridge

- Plane truss of a steel bridge: 5 spans of length 3m, height 2m

- Loads:
  - Dead loads (on the joints of each bar)
  - Live loads: Trucks 60t (uniformly distributed to the upper joints)
  - Horizontal seismic (percentage of vertical) (uniformly distributed to the upper joints)



Example 1: Size optimization of bridge

- Four categories of sections of bars:

```
1. LOWER    : lower horizontal bars (blue)
2. OBLIQUE : oblique bars             (magenta)
3. UPPER    : Upper horizontal bars (green)
4. VERTICAL: vertical bars            (cyan)
```

- All categories of sections are rectangular and initial (lowest) feasible dimensions for all categories are:

  0.09 × 0.09 m

- Constraints for all categories:

  0.05 - 0.10 m with step 0.01 m

- Optimization algorithm: PQN with max 70 iterations

- Optimization objective function: weight

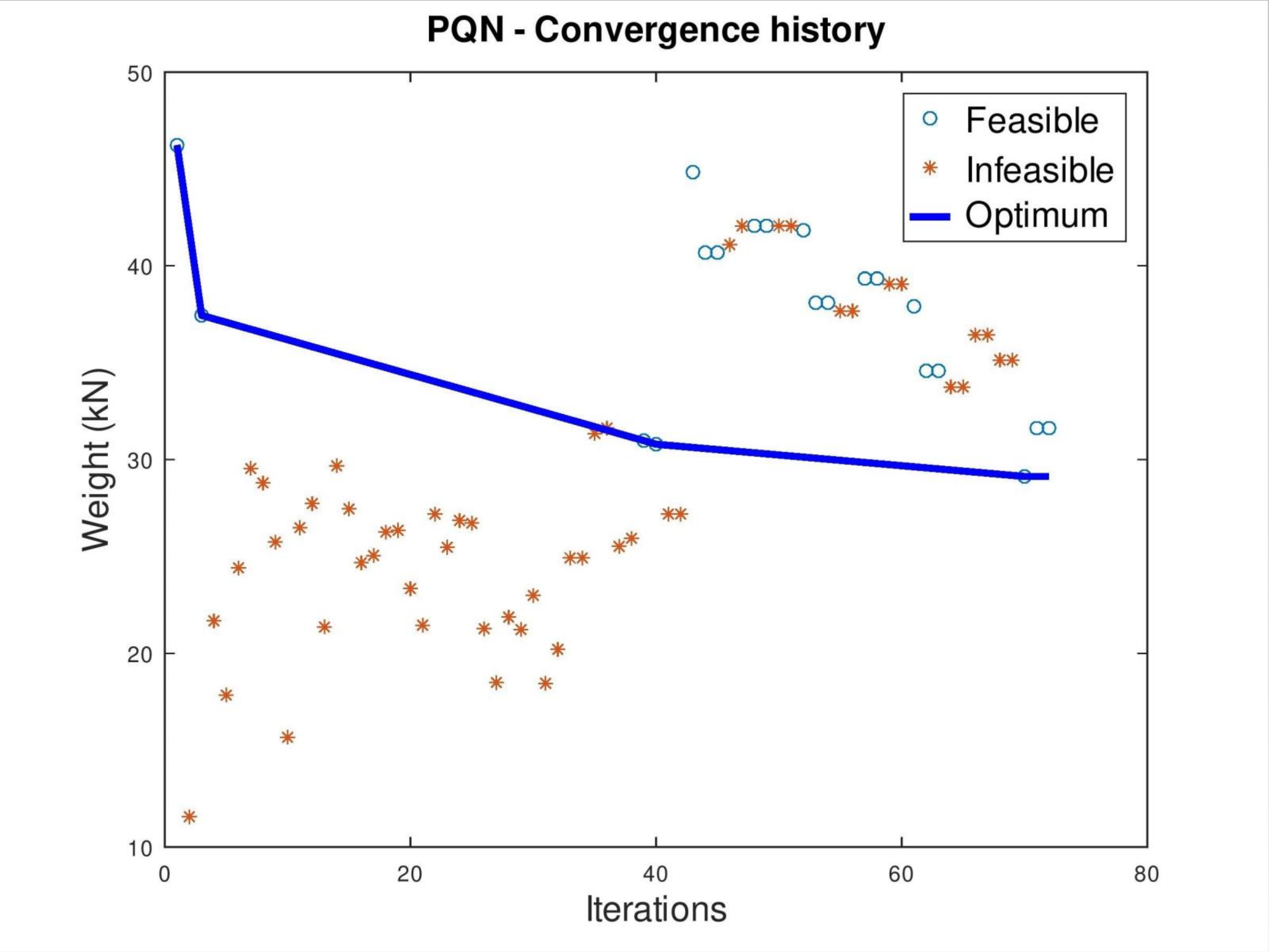
Example 1: Size optimization of bridge

- 22% weight improvement over initial (naive) solution:

Category	Initial	Optimized
LOWER (m)	0.09×0.09	0.05×0.06
OBLIQUE (m)	0.09×0.09	0.09×0.10
UPPER (m)	0.09×0.09	0.06×0.09
VERTICAL (m)	0.09×0.09	0.09×0.09
Weight (kN)	37,443	29,128

- The algorithm performed 69 iterations (analyses)
- Total time: 1minute
  - Optimization overhead time is dwarfed by the time the structural software takes for one analysis

Example 1: Size optimization of bridge



Conclusions

- SOCP: an effective structural optimization computing library was presented
- The library is general, versatile and supports arbitrary constraints
- Straightforward and fast integration into existing structural analysis software
- Further development:
  - more optimization algorithms
  - GUI

ADDING OPTIMIZATION CAPABILITIES TO EXISTING STRUCTURAL ANALYSIS SOFTWARE WITH SOCP: A CASE STUDY

Thank you for your attention

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INTERNATIONAL CONGRESS ON MECHANICS

22-25.09.2019 | THESSALONIKI, GREECE

in honor of Professor Ioannis Vardoulakis
on the occasion of 10 years from his death

P R O G R A M M E

15:00
15:20 **Adding Optimization Capabilities to Existing Structural analysis Software with Ocp: a Case Study**
Athanassios Stamos, Nikos Lagaros, George Kazakis, Stefanos Sotiropoylos, Nikolaos Kallioras

15:20
15:40 **Reduced Order Modeling Methods in topology Optimization**
Nikos Lagaros, Athanasios Rallis, George Kazakis

15:40-16:00	**COFFEE BREAK**

16:00-18:00 Amphitheater I	**Mo.SS01.d Special Session in the Memory of Ioannis Vardoulakis** **Chairs:** Panos Papanastasiou, Ioannis Stefanou

16:00
16:20 **A Discrete Element Method approach for the Preservation of the architectural Heritage against Explosions**
Filippo Masi, Ioannis Stefanou, Paolo Vannucci, Victor Maffi-Berthier

16:20
16:40 **Michelangelo's David Or aphrodite of Milos: Who is more Resistant to Blast Loads?**
Filippo Masi, Ioannis Stefanou, Paolo Vannucci, Victor Maffi-Berthier

16:40
17:00 **Fault Gouge Behavior During Seismic Slip Using 3d Dem**
Efthymios Papachristos, Ioannis Stefanou, Jean Sulem

17:00
17:20 **Bond-Based Micropolar Peridynamic Simulation of Fracture initiation in Quasi-Brittle Materials**
Vito Diana, Joseph Labuz, Luigi Biolzi

17:20
17:40 **Characterization of Rock Masses Using Oriented Drill Coring Techniques, Statistical and Geostatistical Methods**
George Exadaktylos

17:40
18:00 **Constructing a Granular Hydrodynamic Framework That Captures Rheological Observations**
Ebrahim Alaei, Benjy Marks, Itai Einav

16:00-18:00 Amphitheater II	**Mo.MS08 Contact Mechanics and Applications to Fretting Fatigue and Wear** **Chairs:** Antonios E. Giannakopoulos, Thanasis Zisis

16:00
16:20 **Instrumented indentation of a Prestretched Hyperelastic Substrate**
Antonios Giannakopoulos, Thanasis Zisis

Σχόλια - Προβλήματα - Παρατηρήσεις

Δεν υπήρχαν παρατηρήσεις

	Επιστημονικός Υπεύθυνος Έργου	Συντονιστής Έργου
Υπογραφή:		
Ονοματεπώνυμο :	Ν. ΛΑΓΑΡΟΣ	Χ. ΚΩΣΤΟΠΑΝΑΓΙΩΤΗΣ
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