Course Description

- **Instructor**
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- **Class time**
  - Saturday- Monday 10:30-12:00

- **Course evaluation**
  - Mid-term (25%)
  - Final exam (40%)
  - Quiz (5%)
  - Exercise (30%)
Course Description (Continued ...)

- **Mid-term session:**
  - Monday: 8th Ordibehesht 1393, 10:30 ~ 12:30

- **Final Exam:**
  - Saturday: 24th Khordad 1393, 15:00 ~ 17:30

- **Reference:**
  - Benhabib, Beno; “Manufacturing: Design, Production, CAD/CAM, and Integration”, 2003, Marcel Dekker Inc, New York

Course Description (Continued..)

- **Contents:**
  - Introduction to CAD/CAM/CAE systems (5 sessions)
  - Components of CAD/CAM/CAE systems (2 sessions)
  - Geometric modeling systems (3 sessions)
  - Optimization in CAD (5 sessions)
  - Rapid prototyping and manufacturing (3 sessions)
  - Virtual engineering (2 sessions)
  - Product Life Cycle Cost Model (2 sessions)
  - Computer-Based Design and Features/Methodologies of Feature Representations (5 sessions)
  - Feature-Based Process Planning and Techniques (3 sessions)
  - Collaborative Engineering (2 sessions)
Course Description (Continued..)

- Contents:
  - Optimization in CAD
    - Optimization of optimization problems
  - Treatments of constraints
  - Search models
  - Simulated annealing
  - Genetic algorithms
  - Structural optimization

Introduction to CAD/CAM/CAE systems
Geometric modeling systems

* Optimization in CAD

* Design parameterization
  * Designing a cylindrical pressure vessel: the parameter would be the mean diameter, the thickness, the height

* Depending on the situation some parameters can have constraints.

* The parameters which are going to be optimized are called Optimization Variables and the performance index is called Objective Function.
**Geometric modeling systems**

- Optimization in CAD
  - Design parameterization

\[ X^* \in \mathbb{R}^n \text{ so that } F(X^*) = \min F(X) \]

subject to:

\[ X_l \leq X^* \leq X_u \]

\[ G_i(X^*) \geq 0 \quad i = 1, 2, \ldots, m \]

and

\[ H_j(X^*) = 0 \quad j = 1, 2, \ldots, q \]

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**Geometric modeling systems**

- Optimization in CAD
  - Design parameterization

- Terms:
  - Feasible design (acceptable design)
  - Regional constraints (Side constraints)
  - Behavior constraints (functional constraints)

- The objective function \( F(X) \) can be interpreted to be a surface face of dimension “n” embedded in a space of dimension “n+1”
Geometric modeling systems

- Optimization in CAD
  - Design parameterization
  - Treatment of constraints
    - For bounds we can restrict the design variables to stay within the specified bounds
    - For equality constraints the dimension of the design space is reduced by one for each constraint
      - Hence we may try to eliminate one design variable for each equality constraint.
    - For inequality constraints, we can modify the objective function to include the effect of the constraints
      - A penalty function may be added

\[ P(X) = \begin{cases} 
0 & \text{for } X \in \mathbb{R}^n_f \\
\infty & \text{for } X \notin \mathbb{R}^n_f 
\end{cases} \]

\[ D(X) = F(X) + P(X) \]
Geometric modeling systems

* Optimization in CAD
  * Design parameterization
  * Treatment of constraints
    * Exterior penalty function

\[ D(X, \rho) = F(X) + \frac{1}{\rho} S(X) \]

\[ \min D(X, \rho_k) = \min \left[ F(X) + \frac{1}{\rho_k} \left( \sum_i \delta_j |G_i(X)|^\alpha + \sum_j |H_j(X)|^\beta \right) \right] \]

\[ S(X) = \sum_i \delta_j |G_i(X)|^\alpha + \sum_j |H_j(X)|^\beta \]

\[ \delta_j = \begin{cases} 0 & \text{if } G_j(X) \geq 0 \\ 1 & \text{if } G_j(X) < 0 \end{cases} \]

\[ S(X) = 0 \quad \text{if } X \in R^d_f \]

\[ S(X) > 0 \quad \text{if } X \not\in R^d_f \]

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Geometric modeling systems

* Optimization in CAD
  * Design parameterization
  * Treatment of constraints
    * Interior penalty function (no equality constraint may exist)

\[ G_i(X) \geq 0 \quad i = 1, 2, \ldots, m \]

\[ B(X) = \frac{1}{G_i(X)} \]

\[ D(X, \rho) = F(X) + \rho B(X) \]

\[ \min D(X, \rho_k) = \min \left[ F(X) + \rho_k \sum_i \frac{1}{G_i(X)} \right] \]
Geometric modeling systems

- Optimization in CAD
- Design parameterization

Interactive optimization of plate girder bridges subjected to moving loads

H Adeli and K Y Mak

Program 1
Minimize

\[ y_0(x) = \sum_{i=1}^{T_0} \sigma_{oi} c_{oi} \prod_{n=1}^{N} x_{in}^{e_{imn}} \] (5)

subject to

\[ y_m(x) = \sum_{t=1}^{T_m} \sigma_{mt} c_{mt} \prod_{n=1}^{N} x_{in}^{e_{mtn}} \leq \sigma_m \] (6)

\[ x_n > 0 \] (7)

where \( M \) is the number of constraints; \( N \) is the number of design variables; \( m = 1, 2, 3, \ldots, M; n = 1, 2, 3, \ldots, N; x_n \) is the \( n \)th design variable; \( T_0 \) is the number of terms in the objective function; \( T_m \) is the number of terms in the \( m \)th constraint; \( \sigma_{0k} = \pm 1; \sigma_{mt} = \pm 1; \) and \( \sigma_m = \pm 1. \) Note that \( c_{0k} \) and \( c_{mt} \) are the absolute values of coefficients of the \( k \)th term in the objective function and the \( m \)th constraint respectively. However, \( a_{e_{imn}} \) and \( a_{e_{mtn}} \) are unrestricted in sign.
**Geometric modeling systems**

* Optimization in CAD
* Design parameterization

For an unstiffened plate girder with a uniform cross section throughout its length, the objective function is written as

\[
W = \rho L [2b_t t_i + h t_w]
\]  
(11)

For a stiffened plate girder, the objective function is

\[
W = \rho \left[ 2b_t t_i L + h t_w L + \alpha h b_t t_i \sum_{i=1}^{N_S} N_i \right]
\]  
(12)

where \(W\) is the total weight of the plate girder, \(\rho\) is the unit weight of steel and \(L\) is the total length of the girder. In the case of stiffened plate girders, \(\alpha\) distinguishes whether single or double stiffeners are used, and is defined as

\[
\alpha = \begin{cases} 
1 & \text{for single stiffeners} \\
2 & \text{for stiffeners used in pairs} 
\end{cases}
\]  
(13)

The quantity \(N_S\) is the number of spans, and \(N_i\) is the number of intermediate transverse stiffeners in the \(i\)th span.

**DESIGN CONSTRAINTS**

Design for maximum design loads

For homogeneous plate girders, the requirement for maximum moment strength is written in the following GGP form:

\[
\frac{6M_{c}}{F_y b_i t_i} h^{-2} t_w^{-3} + \frac{12M_{u}}{F_y b_i t_i} h^{-2} t_w^{-3} - 8b_t t_i h^{-2} t_w^{-1} \\
- 6b_t t_i h^{-2} t_w^{-3} - 12b_t t_i h^{-2} t_w^{-3} \leq 1
\]  
(14)

where \(F_y\) is the flange yield stress. For hybrid plate girders, this requirement is written as:

\[
\frac{3M_{c}}{4F_y_b_i t_i} + M_{u} h^{-2} t_w^{-3} + \frac{3M_{u}}{2F_y b_i t_i} + \frac{M_{c} h t_w}{4F_y b_i t_i} \\
- \left[ \frac{\rho - \rho'}{32} \right] h t_w \frac{h t_w}{b_i t_i} - \left[ 3 \rho - \rho'' \right] \frac{h t_w}{8b_t t_i} \\
- \left[ 2 + 3 \rho - \rho'' \right] \frac{h t_w}{16b_t t_i} - \left[ \frac{\rho - \rho'}{4} \right] \frac{h t_w}{b_i t_i} \\
- \frac{3h}{2t_i} \frac{3h}{4t_i} \leq 1
\]  
(15)
**Geometric modeling systems**

* Optimization in CAD
* Design parameterization

**A structural optimisation technique**

J. A. Ellis
P. E. West
**Geometric modeling systems**

- Optimization in CAD
- Design parameterization

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**Optimum Design of a Simply Supported Pre-Tensioned Concrete Roof Purlin**

The problem which we wish to solve can be stated in the following form:

A purlin is to be designed as economically as possible for a span of \( L \) ft. and a load of \( w \) lb./ft. It is to be precast in a factory, and is designed to be handled at any point along its length during transport and erection. The permissible stresses at handling and under working load are given for both tension and compression. Also given are:

(a) Concrete cover required at both top and bottom flanges.
(b) The cost of concrete and steel.
(c) The maximum permitted overall depth of the beam.
(d) The safety factor for the ultimate moment and ultimate shearing force.
(e) The U.T.S. and dimensions of the tensioning steel to be used.
(f) The loss ratio for the prestressing force.
(g) The horizontal and vertical separation required between the prestressing wires.

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The object of the design procedure is to design that beam for which the total cost of materials is minimised and which satisfies the following constraints:

(1) The maximum permissible compressive stress in the bottom flange must not be exceeded during handling.
(2) The maximum permissible tensile stress in the top flange must not be exceeded during handling.
(3) The maximum permissible tensile stress in the bottom flange must not be exceeded under working load.
(4) The maximum permissible compressive stress in the top flange must not be exceeded under working load.
(5) The ultimate shear stress in the web must not exceed the maximum tensile stress permitted. Symbolically the following five constraints must hold:

\[
\frac{f_{ct}}{\alpha} + \frac{M_{\text{min}}}{Z_{1}} - \frac{P_{l}}{A} + \frac{P_{e_{s}}}{Z_{1}} > 0
\]

\[
\frac{P_{i}}{A} + \frac{P_{e_{s}}}{Z_{1}} + \frac{M_{\text{min}}}{Z_{2}} - f_{\text{min}} > 0
\]

\[
R_{o} \left( \frac{P_{i}}{A} - \frac{P_{e_{s}}}{Z_{1}} \right) - \frac{M_{w}}{Z_{1}} - f_{\text{minw}} > 0
\]

\[
f_{cw} = \frac{M_{w}}{Z_{2}} - R_{o} \left( \frac{P_{i}}{A} + \frac{P_{e_{s}}}{Z_{2}} \right) > 0
\]

\[
f_{b} = -\frac{1}{2} \sqrt{f_{s}^{2} + 4f_{s}^{2} + C_{r} > 0}
\]

(6) The overall depth shall not exceed that permitted, \( x_{s} < D_{\text{max}} \).

(7) The geometry of the beam shall be practical, that is the sum of the depth of the flanges shall not exceed the overall depth.

(8) The depth of the flanges shall be greater than a certain fraction of their width.

(9) The concrete cover at any wire shall not be less than specified.

(10) The horizontal and vertical separation of the wires shall be that specified.

(11) The numbers of wires in top and bottom flanges shall be integral.

(12) The dimensions of the section variables will be given to the nearest \( \frac{1}{8}, \frac{1}{4} \) or 1 in, as required.

(13) The reinforcement in the bottom flange will be sufficient for ultimate moment considerations.
Geometric modeling systems

* Optimization in CAD
* Design parameterization