AXIAL SYSTEMS

in compression and tension

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Structure Systems & Structure Behavior

INTRODUCTION TO STRUCTURAL CONCEPTS

SKELETON STRUCTURES

- Axial Systems
- Beams
- Frames
- Arches
- Cable-supported Structures

SURFACE STRUCTURES

- Membranes: beams, walls
- Plates: slabs
- Hard shells
- Soft shells: tensile membranes
- Hybrid tensile surface systems: tensegrity

SPACE FRAMES

LATERAL STABILITY OF STRUCTURES

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SKELETON STRUCTURES

PLANAR STRUCTURES

Axial force systems

- TRUSSES
- STAYED STRUCTURES

Flexural force systems

- BEAMS

Flexural-axial force systems

- FRAMES
- ARCHES

SPATIAL STRUCTURES

- SPACE FRAMES
- CABLE STRUCTURES
- COMPOSITE STRUCTURES

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Examples of **AXIAL STRUCTURE SYSTEMS** include, for instance,

- trusses
- compression-tension roof enclosure systems
- lateral bracing of frames
- suspended glass walls
- battered piles
- polyhedral domes
- space frame structures
- cable-supported structures: e.g. beams, roofs
- air-supported structures, air members
- etc.

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COLUMNS

COMPRESSION MEMBERS

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Bundeskanzleramt, Berlin, 2001,
Axel Schultes

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Wanli University, Ningbo

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Guangzhou Baiyun International Airport, 2004, Parsons

The Luxembourg Philharmonie, Luxemboug, 2007, Portzamparc

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The Aluminum Forest ,Utrecht, Netherlands, 2001, M.de Haas

Kanagawa Institute of Technology
Workshop, Kanagawa, Japan, 2007, Junya Ishigami + Associates
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The Netherlands Architectural Institute, **Rotterdam, 1993, *Jo Coenen Arch***

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Indianapolis International Airport, Aerodesign Group Arch, 2008

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Indianapolis International Airport, Aerodesign Group Arch, 2008

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Members in compression have the potential to buckle: to suddenly lose the ability to carry load my moving laterally with respect to the load. In some cases, a member may buckle about the **strong axis** direction (based on a strong axis bending shape), or a **weak axis** direction, as shown below. The allowable stress for each is calculated using appropriate **k**, **L**, and **r** properties for the direction.

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The load which causes a member to **buckle elastically** depends on the following member properties:
The unbraced length: **L**
The cross section size and "spread-outness": **I**
The material stiffness: **E**
The end conditions are also important, since they change the effective length of the member. This is accounted for by an "***effective length factor***", denoted by **k**.

$$f_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 EI}{(kL)^2 A} = \frac{\pi^2 E}{(kL)^2}\left(\frac{I}{A}\right) = \frac{\pi^2 E}{(kL)^2} r^2 = \frac{\pi^2 E}{\left(\frac{kL}{r}\right)^2} \qquad r = \sqrt{\frac{I}{A}}$$

$$F_{cr} = \frac{f_{cr}}{F_s} = \frac{\pi^2 E}{F_s\left(\frac{kL}{r}\right)^2}$$

The following table shows effective length factors:

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Effective Length Factor, K

- To account for “Axial-Flexural Buckling”
- Indicates the “total bent” length of column between inflection points
- Can vary from 0.5 to Infinity
- Most common range 0.75 to 2.0

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K = 0.5	K = 0.7	K = 1	K = 1	K = 2	K = 2
(a)	(b)	(c)	(d)	(e)	(f)

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THE STIFFNESS FACTOR "K" FOR BRACED AND UNBRACED FRAMES

NO SIDESWAY

SIDESWAY

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Elephant Temple, Bombay

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Sagrada Familia, Barcelona, Antonio Gaudi

@Seismicisolation

Expo Dach, Hannover EXPO 2000,

Thomas Herzog, Julius Natterer

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Theatre Erfurt, 2003, Joerg Friedrich

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Atrium **Germanisches Museum, Nuremberg, Germany**

Altmarkt Galery, Dresden

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Ningbo Air Terminal

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Petersbogen shopping center, Leipzig, 2001, HPP Hentrich-Petschnigg

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File Edit View Define Bridge Draw Select Assign Analyze Display Design Options Tools Help
3-D View
3-D View
X0.00 Y0.00 Z0.00
GLOBAL
KN, m, C
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Trees

Eco House Prototype, Malibu, CA, Peter Jon Pearce, 2009

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BEAM COLUMNS

INLINED COLUMNS, FRAMES

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Looped Hybrid Housing, Beijing, 2008,
Steven Holl

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What is Slenderness Effect

I. $M_c = P.e$

Short Column

II : $M_c = P(e + \Delta)$

Long Column

Column Capacity (P-M)

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Green roofs, **Vancouver Civic Centre West**, LMN + DAQ/MCM, 2009

Vancouver Civic Centre West, LMN + DAQ/MCM, 2009

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Beijing

@Seismicisolation

Downtown Ningbo, 2002, Qingyun Ma

Dresdner Bank, Verwaltungszentrum, Leipzig, 1997, Engel und Zimmermann Arch

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Interchange Terminal Hoenheim-Nord, Strassbourg, 2002, Zaha Hadid

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CABLES

TENSION MEMBERS

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Golden Gate Bridge, San Francisco, 1937, Joseph Strauss and Irwing Morrow

Sundial Bridge, Redding, CA, 2006, Santiago Calatrava

IAKOV CHERNIKHOV

Throughout this process we shall colour our forms in different ways:
a. as overall colour;
b. shaded off from the corners;
c. shaded off from the edges;
d. as a transparent wash;
e. densely and dead;
f. lightly;
g. jaunty, and so on.2

SOURCES: 1: P-p.84; 2: A-p.18; Chernikhov's coloured drawings: 1-R: Collection A Chernikhov; P-No.83; P-No.34; P-No.33. Next two pages, 1-R: top:AP-No.38;AP-No.26;AP-No.10; below:AP-No.13;A P-No.88;AP-No.70.

A rigorously constructive and compact combination of architectural elements of the simplest volumetric type, forming an industrial building. Coloured plane by plane in two hues, using the effect of 'shading off to nothing'.

A compactly constructive building of monolithic character. A combination of diverse closed and complete volumes with their main masses clearly articulated.

Experiments with structure, Russian Constructivism

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New York, Piano, 2004, X-bracing of high-rise building

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Aachen, Germany

Cable-supported structures

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Bollman Suspension and Trussed Bridge, Savage, Maryland, 1869

Kempinski Hotel, Munich, Germany, 1997, *H. Jahn/Schlaich*:

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Hongkong Bank, Honkong, 1985, Foster + Arup

Pompidou Center, Paris, 1977

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Centre George Pompidou, Paris, 1977, Piano & Rogers

Centre George Pompidou, Paris, 1977, Piano & Rogers

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Petersbogen shopping center, Leipzig, 2001, HPP Hentrich-Petschnigg

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Stuttgart Airport Terminal **Stuttgart, Germany, 1991, von *Gerkan & Marg***

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Patcenter, Princeton, USA, 1984, Rogers

Shanghai-Pudong International Airport, 2001, Paul Andreu principal architect, Coyne et Bellier structural engineers

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Milleneum Bridge, London, 2000, Foster/Arup

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The Munich Airport Business Center, **Munich, Germany, 1997, *Helmut Jahn Arch***

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Sony Center, Potzdamer Platz, Berlin, 2000, Helmut Jahn Arch., Ove Arup USA Struct. Eng

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Munich Olympic Stadium, 1972, Frei Otto

Space needle, Hirshhorn, Washington, 1968, Kenneth Snelson

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SPHRERICAL ASSEMBLY OF TENSEGRITY TRIPODS

TRUSSES

COMPRESSION-TENSION MEMBERS

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TRUSSES are typical examples of ***axial structure systems*** . Because of their simplicity of behavior they provide an ideal introduction to computer analysis. Trusses are composed of ***frame elements*** ,which are modeled as straight lines connecting two joints ***I*** and ***J*** which are also called *nodes*. It is assumed that the members in trusses are **pin-connected** and subject only to **joint loads**, hence **only axial internal member forces are generated in the truss.**

For **determinate structures** the effect of material and member sizes is in the first introduction to structural software disregarded (i.e. use using either elements with zero moments of inertia or using default setting), since member stiffness has no effect on the magnitude of internal member forces, however **deflection results can not be used**.

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Atrium **Germanisches Museum, Nuremberg, Germany**

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Palladio's Trusses, 1580

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Project, **Nationaltheater**, Mannheim,
1953, Arch.: Ludwig Mies van der Rohe

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George Washington Bridge Bus Station , New York, 1963, Pier Luigi Nervi

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Gund Hall, Harvard U., Cambridge, 1972, John Andrews

Hancock Tower, Chicago, 1970, Bruce Graham / SOM

The Leadenhall Building, London, 2010,
Rogers Stirk Harbour + Partners, Arup

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Bank of China, Hong Kong, 1989, Arch.: I.M. Pei, Ing.: Robertson, Fowler and Associt.

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Highrise Beijing, 2006

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eccentric trussess

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Hongkong Bank, Hong Kong, 1985, Foster/Arup

@Seismicisolation

Centre Georges Pompidou, Paris, 1977, Arch: R. Piano + R. Rogers, Ing: P. Rice (Ove Arup & Partners

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staggered truss system

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TKFC Yum! Center, Louisville Ky, 2010,
Populous Arch, , Walter P Moore Struct. Eng.

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Trade Fair Centre, parking garage
Stuttgart, 2007, Wulf & Partners

@Seismicisolation

NOVARTIS CAMPUS FABRIKSTRASSE , Basel, Switzerland, JOSE RAFAEL MONEO

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Rotterdam

@Seismicisolation

Seoul National University Museum, 2006, Rem Koolhaas

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SAP2000 v12.0.2 Advanced C - Soul

File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Tools Help

Zoom In One Step (Shift+F8)

Axial Force Diagram (gravity)

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Right Click on any Frame Element for detailed diagram

GLOBAL KN, m, C

start SAP2000 v12.0.2 Ad... Seoul - Microsoft Word EN 5:06 AM

SAP2000 v12.0.2 Advanced C - Soul

File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Tools Help

Axial Force Diagram (W)

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1 Areas, 3 Edges Selected

GLOBAL KN, m, C

start SAP2000 v12.0.2 Ad... Seoul - Microsoft Word EN 5:14 AM

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Library Gainesville, FL

@Seismicisolation

@Seismicisolation

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POPS, Arcadia, Oklahoma, 2008,
Elliott + Associates Architects

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1. *Main entry*
2. *Table seating*
3. *Soda bottle display*
4. *Mechanical*
5. *Office*
6. *Kitchen*
7. *Soda counter*
8. *Counter seating*
9. *Booth seating*
10. *Patio entry*
11. *Patio seating*
12. *Digital jukebox*
13. *Soda kiosk*
14. *Vintage soda coolers*
15. *Self-serve counter*
16. *Product gondolas*
17. *Soda coolers*
18. *Checkout counter*
19. *Steel pipes*
20. *Sandstone walls*

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16. *Product gondolas*
17. *Soda coolers*
18. *Checkout counter*
19. *Steel pipes*
20. *Sandstone walls*

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Investigate a basic 15-ft (4,57-m) high, 30-ft (9,14-m) span, triangular, hinged truss unit using SAP2000. Apply vertical, horizontal, or combined single loads of 1-k = 4,45kN at the joints as indicated on the drawing; assign zero to self-weight. Disregard the effect of material and member sizes (i.e. use default setting), since member stiffness in determinate structures has no effect on the magnitude of internal member forces, however do not use deflection results.

Study the load flow effect due to change of:

GEOMETRY: profile, crown location, roof slope, inclination of bottom chord, etc.

LOAD ARRANGEMENT: load location, load direction

SUPPORT LOCATION and ORIENTATION (i.e. rotate supports)

Start with the basic symmetrical regular truss, and then reshape the unit and run the case analysis, and so on. Use a 5x5-ft (1,524x1,524-m) grid to construct the layout of the truss. Show the axial force flow with numerical values, and show the reaction forces. **Study the relationship of member tension and compression so you can develop a feeling for the structure and predict the direction of the force flow.**

Check manually (graphically or analytically) the computer results of member forces and reactions for at least half the cases.

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SAP2000 - Ex.5.1 triangular truss units

File Edit View Define Draw Select Assign Analyze Display Design Options Help

Joint Loads (LOAD1)

Restraint Reactions (LOAD1)

Axial Force Diagram (LOAD1)

Deformed Shape (LOAD1)

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Right Click on any joint for displacement values

Start Animation

Kip-ft

start

TRUSSES

A. Visual Study of...

SAP2000 - Ex.5.1

11:49 A

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The cabin of Mac Dunstan and Linda Grob, in a hillside near Seattle, 2008

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Structural software, ***West Point Bridge Designer***, version 4.1.1, which was developed by Colonel Professor Steve Ressler at the U.S. Military Academy, West Point, NY. (bridgecontest.usma.edu/index.htm).

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SAP2000 - Ex.5.2 truss generation

File Edit View Define Draw Select Assign Analyze Display Design Options Help

Joint Loads (LOAD1)

Axial Force Diagram (LOAD1)

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X-Z Plane @ Y=12.5

Kip-ft

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COMPUTATION OF AXIAL MEMBER FORCES

Generally, two methods can be used: **Method of Joints** and **Method of Sections**

The internal member forces at mid-span are only checked. Therefore, a segment of the truss is investigated by cutting an imaginary section through the truss, (i.e. **method of section)** and looking only to the left free-body. The unknown internal forces in the top, bottom and diagonal members are designated as $\mathbf{N_t}$ and $\mathbf{N_b}$ with the **assumed** direction as shown in the previous free-body that is acting in compression towards the members, and $\mathbf{N_d}$ acting in tension away from the members.

Vertical equilibrium of forces gives the magnitude of the normal force N_d in the diagonal member,

$$\Sigma V = 0 = 2.5 - 2(1) - (N_d /)1, \quad \text{or} \quad \mathbf{N_d = 0.707\ k\ (C)}$$

Rotational equilibrium about the top joint *D* at mid-span yields the magnitude of the bottom chord force N_b.

$$\Sigma M_D = 0 = 2.5(16) - 1(16) - 1(8) - N_b(8), \quad \text{or} \quad \mathbf{N_b = 2.0\ k\ (T)}$$

Rotational equilibrium about the bottom joint *J* yields the magnitude of the top chord force *Nt*.

$$\Sigma M_J = 0 = 2.5(8) - 1(8) - N_t(8), \quad \text{or} \quad \mathbf{N_b = 1.5\ k\ (C)}$$

$$\text{Check: } \Sigma H = 0 = 2.0 - 1.5 - (0.707/)1, \quad \text{OK}$$

The magnitude of the other members in the free-body can be obtained now by the method of joints.

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SAP2000 v11.0.8 Advanced - Example 6.1, analysis of basic truss forms_V11-a

File Edit View Define BrIM Draw Select Assign Analyze Display Design Options Help

Joint Loads (P) (As Defined)
Object Model

Joint Reactions (P)
Analysis Model

Axial Force Diagram (P)
Analysis Model

Deformed Shape (P)
Analysis Model

Right Click on any Frame Element for detailed diagram

GLOBAL Kip, ft, F

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TU Stuttgart, Germany

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Bordercrossing Lichtenbusch, Belgium
near Aachen, 2006

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Petersbogen shopping center, Leipzig, 2001, HPP Hentrich-Petschnigg

Serpentine Joists: Lindhout Architects Headquarters, Brighton, MI, 2008

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Pyramidal Roof Structure

SAP2000 - Example 8.2 pyramid

File Edit View Define Draw Select Assign Analyze Display Design Options Help

Joint Loads (GRAVITY)

Axial Force Diagram (GRAVITY)

Joint Loads (LATERAL)

Axial Force Diagram (LATERAL)

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US Air Force Hangar Projekt, 1951, Arch.: Konrad Wachsmann

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SAP2000 v14.1.0 Advanced C - Tree
File Edit View Define Bridge Draw Select Assign Analyze Display Design Options Tools Help
Deformed Shape (COMB1)
Right Click on any joint for displacement values
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SAP2000 v14.1.0 Advanced C - Tree
File Edit View Define Bridge Draw Select Assign Analyze Display Design Options Tools Help
Axial Force Diagram (COMB1)
Right Click on any Frame Element for detailed diagram
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Sony Site, Potsdamer Platz, 2000, Helmut Jahn

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Sony Center–Esplanade Apartments

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Opposite:
Esplanade Apartments projecting into Forum
5 Plan – upper level
6 Plan – lower level
7 South elevation

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24 9 2001
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Us Airline Terminal, O'Hare International Airport, Chicago, 1987, Helmut Jahn

Mercedes-Benz-Zentrale, Berlin, 2000, Lamm, Weber, Donath und Partner

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San Francisco International Airport, International Terminal, 2001, SOM

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4
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Chongqing Airport Terminal, 2005, Llewelyn Davies Yeang and Arup

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Beijing Airport, Terminal 2
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Original Site Photo

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Application of trusses ranges from the small scale of a joist to the large scale of a deep truss supporting a stadium roof. They are used as roof and bridge structures and as wind bents that is vertical cantilevers, which brace high-rise skeleton structures. Trusses may replace any solid element such as beams, columns, arches, or frames. From a structure system point of view, they may be classified as,

Truss cantilevers, truss beams of various profiles (flat, tapered, pitched, curved, crescent, etc.)

Truss arches

Truss frames forming single or multi-bay structures

The typical truss profiles for roofs are flat, pitched (e.g. triangular, trapezoidal, hip, gambrel) or curved. Trusses may be organized according to the arrangement of members and according to behavioral considerations as:

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Simple trusses are formed by the addition of triangular member units and can be further subdivided into ***regular***, ***irregular*** (e.g. fan trusses), and ***subdivided truss*** systems often used for bridge trusses to give adequate support to the deck (Fig. 5.4, 5.5).

Compound trusses are formed by **addition of simple trusses**. These trusses are not necessarily composed of triangles, indicating that stable trusses can be generated by figures other than triangles (Fig. 5.8)

Complex trusses are neither simple nor compound. Special methods of analysis must be applied to these trusses even if they are statically determinate, since more than three members are attached to each joint, and sections cut through at least four members result in more unknowns than available equations at the location to be investigated (Fig. 5.9).

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TRIANGULAR SOLAR

AP2000 - Fig. 5.4 triangular trusses

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Joint Loads (LOAD1)

Axial Force Diagram (LOAD1)

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Common simple truss types are identified in Fig. 5.5. It is demonstrated in the drawings that the **arrangement of the members** determines which of the members are in tension and in compression under uniform gravity loading along the top chord..

Pratt truss (a.) with diagonals in tension and the verticals in compression,

Howe truss (b.) using compression diagonals and vertical tension members,

Modified Warren truss (c., d.) in which the diagonals are alternately in tension and compression,

Lattice or **double Warren truss** (e.) can be visualized as two superimposed single Warren trusses,

K-truss (f.) in which the top half behaves similar to a Howe truss, while the bottom half behaves like a Pratt truss.

X-truss (g.) often designed as hinged frame truss cross-braced with tensile rods, where the bars are not connected at their point of intersection. Since the diagonals cannot carry compression, the truss reduces to a Pratt truss under the given loading.

Irregular truss (g.): for the shown truss the diagonal bars cross each other without being connected at their point of intersection. The truss reduces to a Warren truss under the given loading. Other examples of irregular simple trusses include fan trusses.

Composite, truss-like structures where struts resist compression and ties tension (for discussion see Ch. 9.1)

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SIMPLE RECTANGULAR TRUSSES

AP2000 - Fig. 5.5 simple rectangular trusses

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Axial Force Diagram (LOAD1)

Joint Loads (LOAD1)

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TU Stuttgart, Germany

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new **Trade Fair Center**, parking garage across A8, 2007, Wulf & Partners

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Museum Marta, Herford, 2005, Frank Gehry

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Airhangar, Munich

Skijump tower, Oberhof, Thueringer, Germany

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Holocaust Memorial Museum,
Washington, 1993,
James Ingo Freed

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Cardinals Stadium, Glensdale, AR, 2006, Peter Eisenman

Cardinals Stadium, Glendale, Ariz, 2006, Peter Eisenman

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The distribution of force flow depends not just on the arrangement of the web members but also on the truss shape. Comparing the basic truss profiles of flat, pitched, and curved trusses under uniform gravity loading, one may conclude:

The curvilinear profile can be considered optimal since it is nearly funicular for the given loading.

The chords of the flat truss are only used efficiently in the mid-span range thereby suggesting the benefit of the shape for larger spans where bending controls.

For the triangular truss the chords are only efficiently used at the supports where the shear is maximum, indicating the advantage of the shape for shorter spans where shear beam action controls.

The trapezoidal truss falls between the parallel and triangular trusses.

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From a point of view of optimum weight, the truss configuration should reflect the **funicular shape** due to the critical external loading so that the chords carry all the loads and the web members are zero and are primarily used for the secondary asymmetrical loading case and for lateral bracing of the compression chord. One may also want to consider the **constant-force design** of trusses, where the force flow along the top and bottom chords is constant. Several examples of efficient truss forms as related to gravity loading, are shown in Fig. 5.6.

A truss should be **curvilinear** in response to uniform load action (e.) with a funicular top chord arch and constant-stress bottom chord; for a fish belly truss the situation is opposite.

However, in the **ideal form**, the vertical web members should be arranged in a radial fashion so that that their extensions intersect at a concurrent point, the center of the circle forming the top (or bottom) arch. For this situation, the forces are constant in the arched top chord and almost constant in the radial web members and the bottom chord (e.).

A truss should be **lens-shaped,** if the loads are shared by the arched top and bottom chords in compression and tension respectively (f.).

A truss should be **pitched** for point loading. In other words, the truss should be **triangular** with respect to a single load (a.), **trapezoidal** for two loads (d.), and of **gambrel** profile for three single loads (c.).

A triangular truss should have a **funicular bottom chord**, if the web columns transfer loads from the top chord to the tensile bottom chord (b.).

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FUNICULAR TRUSSES

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AP2000 - Fig 5.6 funicular trusses

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Axial Force Diagram (LOAD1)

Joint Loads (LOAD1)

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FAN TRUSSES

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AP2000 - Fig.5.7 fan trusses 6

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Axial Force Diagram (LOAD1)

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Compound Trusses

When several simple trusses are connected to each other, they are called compound trusses (Fig. 5.8). Trusses may be connected by:
by three nonparallel bars whose axes cannot cross a common point,
by a single member and common joint,
by replacing members of the main truss with secondary trusses.

Compound trusses can be analyzed by using a combination of the *methods of sections and joints*. For the third truss type, however, remove the secondary truss members and replace them with fictitious members to form the main truss. First figure the reactions and force flow of the secondary trusses, and then apply the reactions as external loads to the main truss.

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000 - Fig.5.8 compound trusses

View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Axial Force Diagram (LOAD1)

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on any Frame Element for detailed diagram

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Complex Trusses

Trusses, which cannot be classified as simple or compound trusses are called complex trusses. Complex trusses may have any member configuration and any number of support conditions as long as Eq. 5.1 is satisfied for statically determinate trusses and they are stable.

To check the computer solution of complex, determinate trusses manually may not be simple, since joints generally have more than three unknowns. In other words, using the *method of joints*, the equilibrium equations for several joints must be set up, and then the equations must be solved simultaneously. Another method of analysis is to reduce the complex truss to a stable simple truss by removing a member and substituting it somewhere else to form a simple truss, called the method of substitute members. For fast approximation purposes of parallel chord trusses, however, use the beam analogy by assuming that the moments are carried by the flanges and the shear by the web members.

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COMPLEX TRUSSES

AP2000 - Fig.5.9 complex trusses
Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d xy xz yz
Axial Force Diagram (LOAD1)
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trestle table by Carlo Molino (1948)

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William J. Clinton Presidential Center , Little Rock, Ark, 2004, James Polshek

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TRUSS ELEVATION

Graphic courtesy Leslie E. Robertson Associates.

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SAP2000 - Ex5.3 truss design
File Edit View Define Draw Select Assign Analyze Display Design Options Help
Frame Span Loads (DEAD)
Axial Force Diagram (COMB1)
Moment 3-3 Diagram (COMB1)
Deformed Shape (COMB1)
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SAP2000 - Ex.5.3 truss design

e Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

Joint Loads (WIND)

6.00

Axial Force Diagram (WIND)

Moment 3-3 Diagram (WIND)

Deformed Shape (WIND)

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Tree geometry

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a.

b.

c.

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The following typical principal steps for performing a finite element analysis, considering only basic, simple structures for preliminary design purposes, are:

CREATE the finite element model by dividing the structure into finite elements – idealize the structure

DEFINE

- GRID SIZE and UNITS
- MEMBER ELEMENTS and NODES: determine the type of elements which are appropriate for you model.
  In SAP2000 you only define elements - all nodes needed by the elements are automatically generated.
  - **Line elements**: truss, beam (beam column), cable
  - **Surface elements**: behavior (membrane-, plate-, shell-elements), shape (quadrilateral, triangular)
  - **3D elements**
- MATERIAL properties: steel, reinforced concrete, other
- MEMBER SECTIONS: geometric properties, shapes from library
- LOADING conditions: static load cases, load combinations

DRAW GEOMETRY: define the geometry of structure, i.e. the location of members on grid

ASSIGN properties, loading, and boundary conditions to the structure

- MATERIAL
- MEMBER SECTIONS
- EXTERNAL SUPPORTS: free, fixed, pinned, roller, spring
- NODAL RESTRAINTS: FRAME END RELEASES, constraints, springs
- EXTERNAL FORCES/DISPLACEMENTS on nodes and members
- DIAPHRAGM CONSTRAINTS
- MEMBER CHARACTERISTICS: clear length, unbraced length
- etc.

CHECK INPUT DATA

ANALYZE select analysis type and run analysis

- DISPLAY the model (e.g. reactions, forces, stresses, deformations and animations)
- EVALUATE and CHECK important results

DESIGN

- MEMBER PROERTIES
- MODIFY MEMBER PROPERTIES

RE-ANALYZE and RE-DESIGN

PRINTING and PLOTTING of results

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