ENGINEERS AUSTRALIA - NORTHERN DIVISION
CONTINUING PROFESSIONAL DEVELOPMENT
22 APRIL 2010

LONG SPANS IN BUILDINGS

Prof. David M Lilley

Aim: to provide information about alternative design solutions

Objective: to illustrate different methods of achieving long spans within buildings

Long Spans in Buildings

- common requirement: large floor area clear of internal columns, with floors above clear space

- floor loads above clear span may be supported by structure or foundation beneath floor, suspended from structure above.

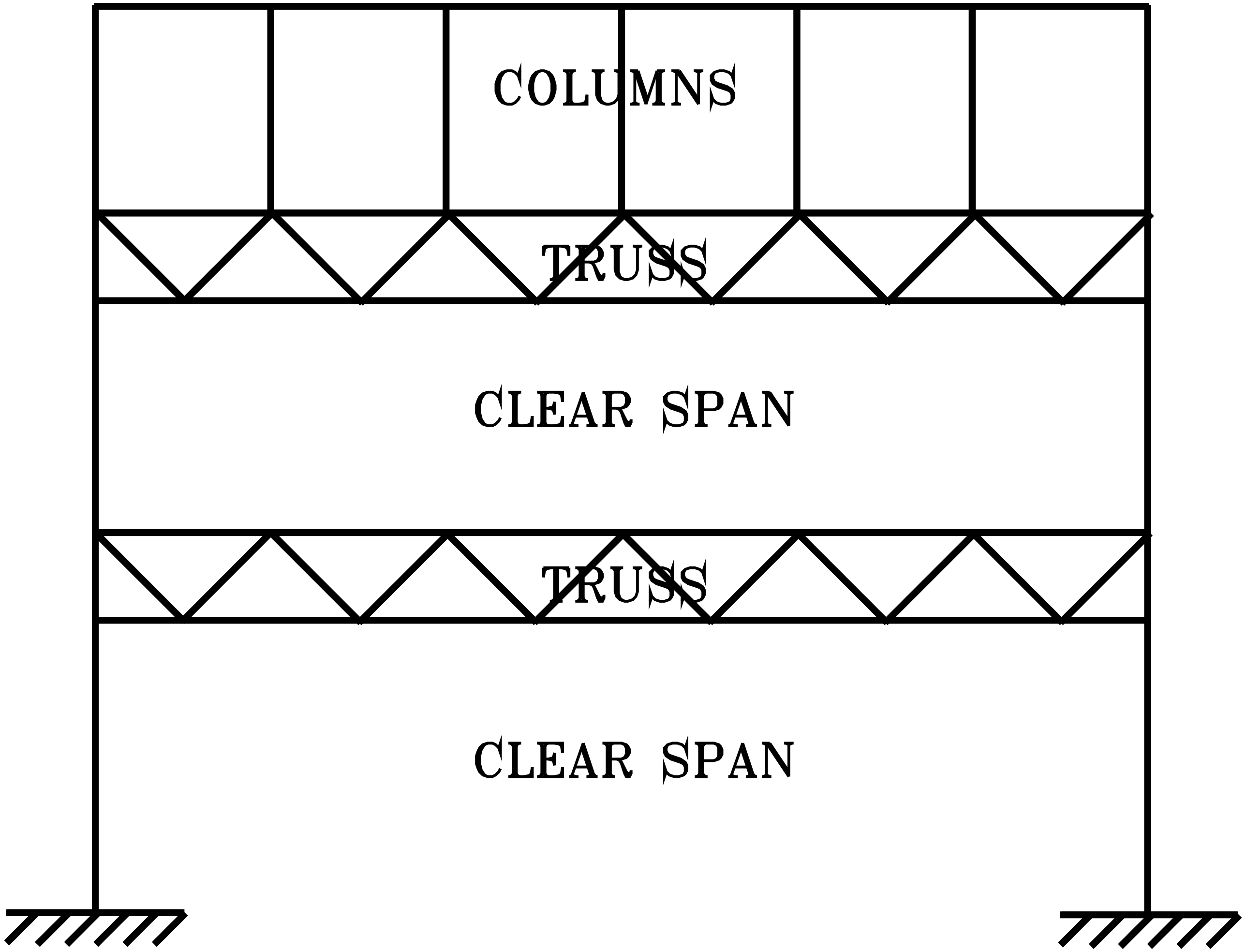

Figure 1

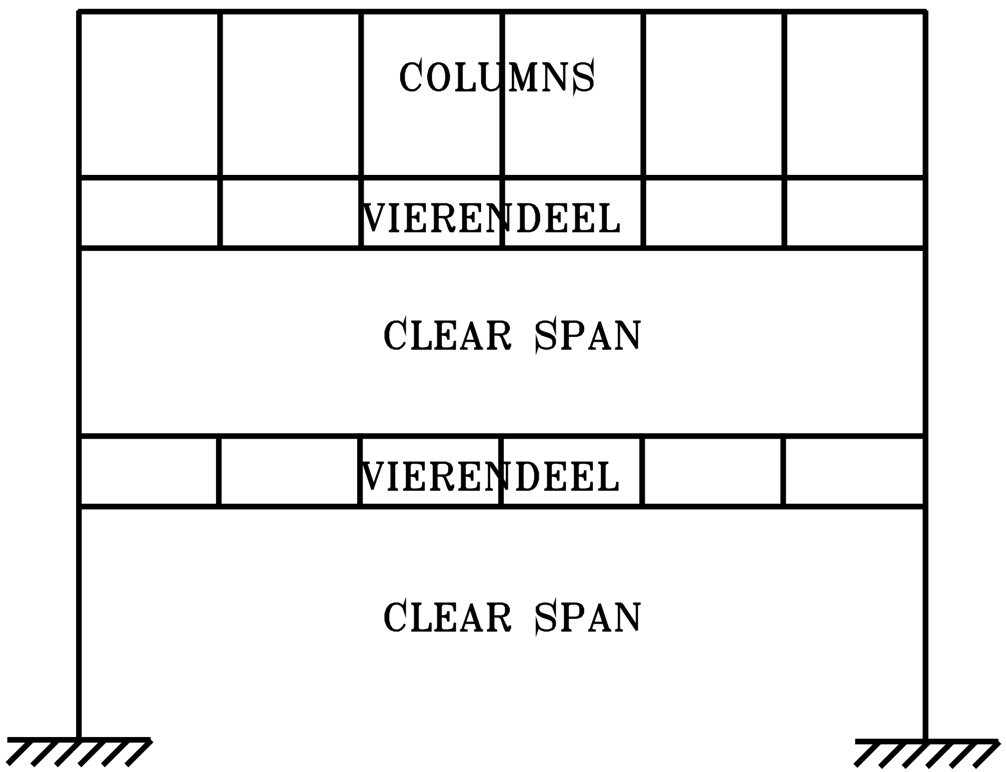

Figure 2

- Vierendeel girders: advantage as no diagonal members to restrict access in utility areas
- caution: possible fabrication problems if large forces produced at connections in Vierendeel girder

- truss at top of structure supports almost all of internal load of structure

- load transferred from each floor into internal columns, causing these to go into **tension**

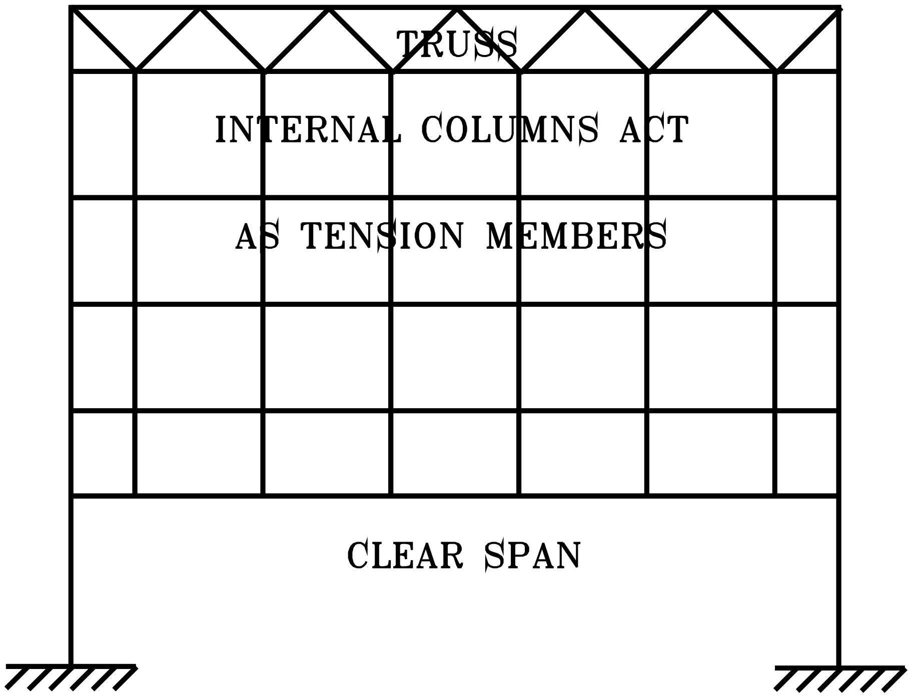

Figure 3

- load then transmitted to outer columns as compressive load, and ultimately to ground through foundations.

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RAPID DESIGN OF STEELWORK TRUSS

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Aim: to inform participants about rapid design of a major structural element, i.e. a truss

Objective: to demonstrate a simple method of design for a steel truss, checking maximum permissible stress and deflection

Rapid Design of Steelwork Truss

- General rule: steel truss under "normal" loads,

  truss depth should be about span / 16 - span / 10

  (top and bottom members stressed to reasonable proportions of their capacity.)

- divide truss into 6 or 8 or 10 equal-sized panels, having vertical members and diagonals (Figure 1)

- assume vertical (downwards) load evenly distributed along truss length

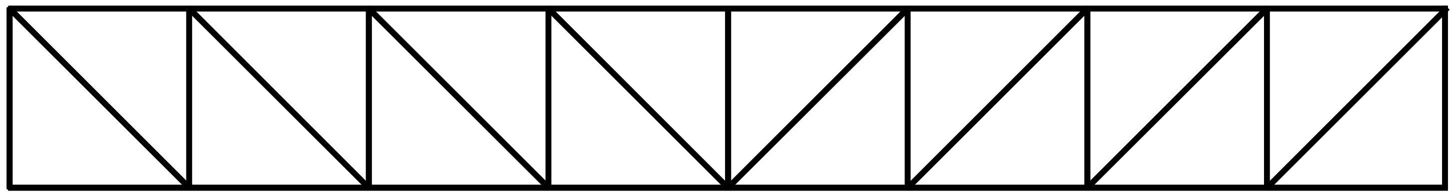

Figure 1

- note **direction** of diagonal members

  (diagonal members in tension, rather than compression, leads to better economy)

- beware of out-of-plane buckling produced by compression in top boom of truss

- following method OK if **adequate restraint to prevent out-of-plane buckling in top boom**

- if inadequate restraint, reduce max allowable stresses by factor of least 2.

- proceed as follows:

i) determine full applied load (dead + imposed load)

horizontal spacing between two adjacent trusses important in determining load on a single truss

ii) assume load applied as UDL (w per metre span) over full span, and analyse as a simply-supported beam

maximum bending moment (mid-span), M, given by

$$M = \frac{w L^2}{8}$$

L = span of truss.

iii) moment resisted mainly by tensile force in lower boom and compressive force in top boom

magnitude, P, of axial forces obtained from "moment" effect, ie. force × distance, d, between centre-lines of boom members.

magnitude, P, of force in each boom is

$$P = \frac{M}{d}$$

iv) axial stress σ in booms at mid-span is

$$\sigma = \frac{P}{A}$$

A = cross-sectional area of one boom members

- assume Factor of Safety = 1.7

and

max. permissible stress

= yield stress / Factor of Safety

- if yield stress = 250 MPa,

  max permissible stress = 250 MPa / 1.7
  = 147.0 MPa = **145 MPa**

- if yield stress = 350 MPa,

  max permissible stress = 350 MPa / 1.7
  = 205.9 MPa = **205 MPa**

- if yield stress = 450 MPa,

  max permissible stress = 450 MPa / 1.7
  = 264.7 MPa = **265 MPa**

NB: higher strength steel normally costs more than lower strength steel

v) rearrange equation to give cross-sectional area to produce maximum permissible stress

cross-section must have an area (expressed in mm^2) which is more than:

$$A = \frac{P}{145} \qquad \text{(Steel Grade 250)}$$

where P is expressed in **Newtons**

vi) deflection at mid-span must also be considered

- deflection from dead load (self weight) important, but visual effect countered by **pre-cambering** truss, if desired

- for **imposed** load treated as UDL (w_L), deflection at mid-span is

$$\frac{5\ w_L\ L^4}{384\ E\ I}$$

E = Young's modulus (200×10^3 MPa for steel)

I = Second moment of area of **truss** at mid-span

$$I = \frac{A \times d^2}{2}$$

- deflection at mid-span of beam or truss due to imposed loads should be less than **span/360**

  using this limiting value, rearrange equations

$$A = \frac{3600\ w_L\ L^3}{384\ E\ d^2}$$

vii) two values for cross-sectional area of each boom members; one from stress, the other from deflection

Higher value is the one to be used.

- choose steel section made from tables of cross-sectional areas.
- vertical and diagonal members made from same size sections as horizontal members
- some economy can usually achieved by reducing section sizes for diagonal and vertical members

Worked Example: Rapid Truss Design

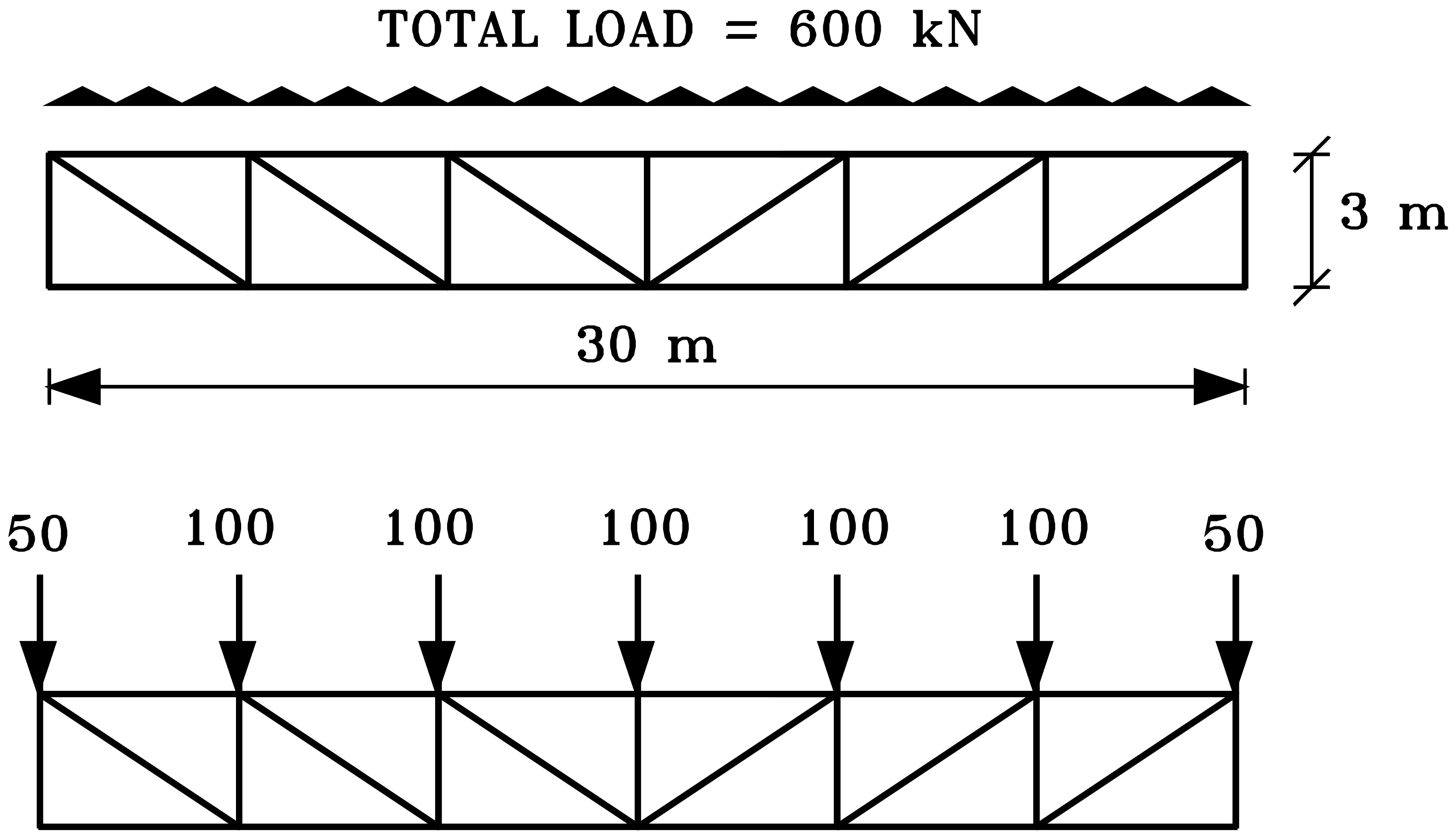

Figure 2

Span = 30 m, Dead load (udl) = 5 kN/m (including self-weight), Imposed load (udl) = 15 kN/m.

Formed from **square hollow section** (Grade 350). maximum permissible stress = 205 MPa

Maximum deflection limited to span/360 (imposed load only).

Sketch elevation of truss. Calculate weight and budget cost of truss, assuming erected steelwork costs A$1950 per tonne.

- total distributed load = 600 kN

M_{MAX} (at mid-span) is given by

$$M_{MAX} = \frac{w_{TOTAL}\ L^2}{8} = \frac{(5 + 15)\ kN/m \times (30\ m)^2}{8} = 2250\ kNm$$

- effective depth (d) of truss assumed to be 3 m.

- Axial load in each of top and bottom booms is

$$P = \frac{M_{MAX}}{d} = \frac{2250\ kNm}{3\ m} = 750\ kN$$

- max. permissible stress (Grade 350) is 205 MPa.

- cross-sectional area A required

$$A = \frac{750 \times 10^3 \text{ N}}{205 \text{ MPa}} = \mathbf{3659 \ mm^2}$$

Maximum deflection is span/360 (= 83.3 mm) under imposed load only.

$$\frac{L}{360} = \frac{5\ w_L\ L^4}{384\ E\ I} = \frac{5\ w_L\ L^4}{384\ E\ \frac{A\ d^2}{2}}$$

$$\Rightarrow \quad A = \frac{3600\ w_L\ L^3}{384\ E\ d^2} = \frac{3600 \times 15 \times 30^3}{384 \times 200 \times 10^6 \times 3^2}$$

$$\Rightarrow \quad A = 2.109 \times 10^{-3}\ m^2 = \mathbf{2109\ mm^2}$$

- previous value for A obtained by considering maximum stress is higher (**3659 mm^2**), and therefore **must** be taken as required cross-sectional area for truss members

- using section tables provided SHS with nearest cross-sectional area greater than this area is 200 × 200 × 5 mm SHS (area = 3810 mm^2) which has a mass of 29.9 kg/m.

- total length of steel section in one truss is

$$2 \times 30 \text{ m} + 7 \times 3 \text{ m} + 6 \times \sqrt{5^2 + 3^2} \text{ m}$$

$$= 116.0 \text{ m}$$

- total weight of steel in the truss is

$$116.0 \text{ m} \times 29.9 \text{ kg/m} = 3468.4 \text{ kg}$$

- cost of erected steelwork is A$1950 per tonne, the total cost of truss is

$$3.4684 \text{ T} \times \text{A\$1950/T} = \textbf{A\$6763}$$

Learning Outcomes:

- ability to devise a scheme for supporting loads above large clear spans in buildings

- ability to produce a simple and quick design of a truss, and to determine section sizes and budget cost - see “Tutorial Questions for Private Study” at end of Notes (and Worked Solutions!).

Tutorial Questions

Question 1: *A steel truss (with horizontal top and bottom booms) is urgently required to give temporary support to a roof structure which has been damaged by severe weather. The truss spans 40 metres and is subjected to an imposed vertical load of 8 kN/metre span, in addition to its own self-weight, which can be assumed to be 0.45 kN/metre span.*

The space available for construction is limited, and the maximum overall height of the truss must not exceed 2.2 metres.

*If the maximum permissible axial stress within the truss must not exceed 205MPa, and the maximum allowable deflection under imposed load is restricted to **span/350**:*

i) provide a sketch of the shape of the truss you would recommend, bearing in mind the immediate requirement for the steelwork and the need for economic design;

ii) use suitable calculations to determine a structural square hollow steel section which you would recommend to be used for the fabrication of the truss;

iii) estimate the cost of the truss, given that the overall cost of erected steelwork can be estimated as A$1800 per tonne.

The value of Young's Modulus for steel can be assumed to be 200 × 10^3 MPa (= 200 × 10^6 kN/m^2).

Question 2: *A steel truss (with horizontal top and bottom booms) is required to span 25 metres and is subjected to an imposed vertical load of 5 kN/metre span, in addition to its own self-weight, which can be assumed to be 0.35 kN/metre span.*

The space available for construction is limited, and the maximum height of the truss must not exceed 1.5 metres. If Steel Grade 350 is to be used (maximum permissible axial stress within the truss is 205MPa), and the maximum allowable deflection under imposed load is restricted to ***span/350****:*

i) provide a sketch of the shape of the truss you would recommend;

ii) *use suitable calculations to determine a steel section which you would recommend to be used for the fabrication of the truss. You should consider SHS, RHS and CHS section, and your recommendation should be based on achieving minimum weight while still meeting all the above design criteria;*

iii) *estimate the cost of the truss, given that the overall cost of erected steelwork can be estimated as A$1880 per tonne.*

The value of Young's Modulus for steel can be assumed to be 200×10^3 *MPa (=* 200×10^6 kN/m^2*).*