Fire Safety Engineering in Japan

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FSE in Japan, a bit of history

- BSLJ(1950)
- Bouka Sopro (1982-86)
  - Initiation of performance based design
- Boutaika Sopro (1993-97)
  - Introduction of PB concept into regulation
  - Elimination of equivalency clause
- PB. BSLJ(2000)
  - Introduction of functional requirements into code

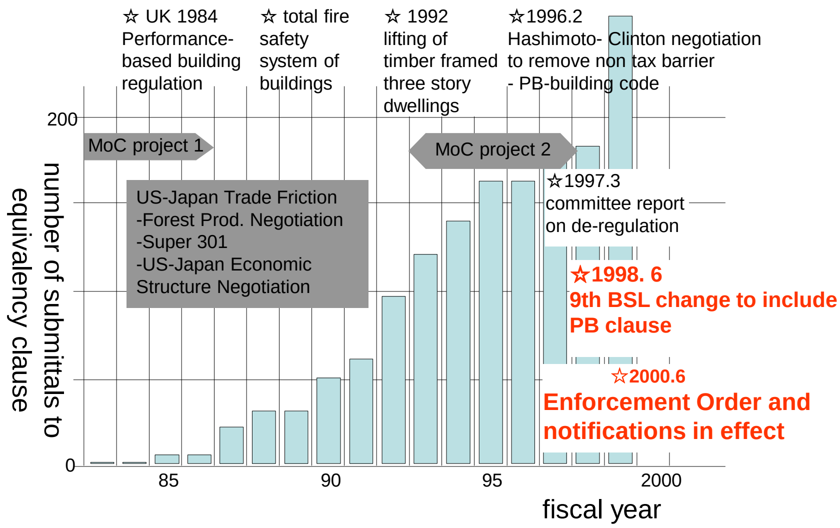
Fire Regulations of Buildings

- Building Standards Law (MLIT)
  - hygiene and safety
    - dairy safety, structural safety in normal, snow, wind, seismic conditions
    - fire safety (passive measures)
      - fire resistance (structural)
      - fire containment (separation element)
      - means of egress
      - equipment (smoke control, emergency lighting, ...)

Fire Regulations of Buildings

- Fire Service Law (FDMA,MHA)
  - fire prevention, protection and management
    - public buildings, apartment house, industrial premise, …
    - active fire measures
      - Detection and suppression
      - escape aid equipment (sign, ladders, …)
      - equipment for fire fighting (smoke control, stand pipe, ...)

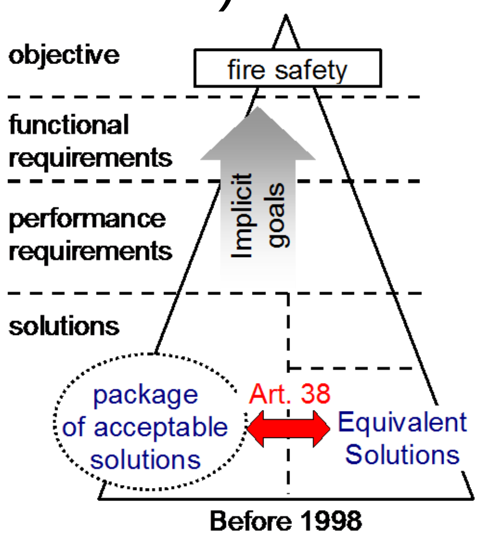
Evolution of performance-based design in BSLJ



Harada et al., 3rd PBC&FSD, June 2000 (Original figure was made by Dr. Takeichi)

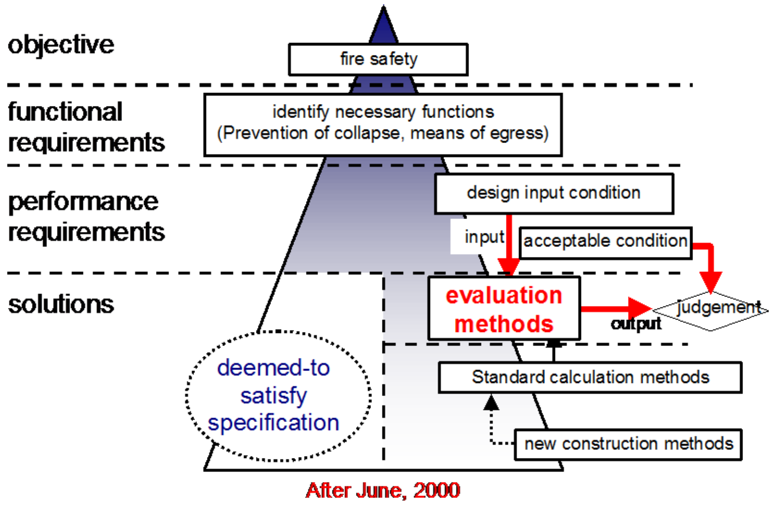
Equivalency Clause, (1986～2000)

"The provisions … shall not apply …, if the Minister of Construction deems … equal or superior to …"



Harada et al., 3rd PBC&FSD, June 2000

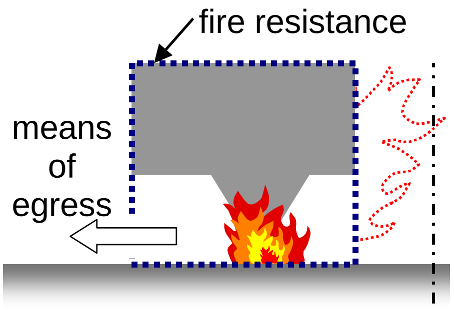
Revision of BSLJ, 2000



Harada et al., 3rd PBC&FSD, June 2000

Functional Statements

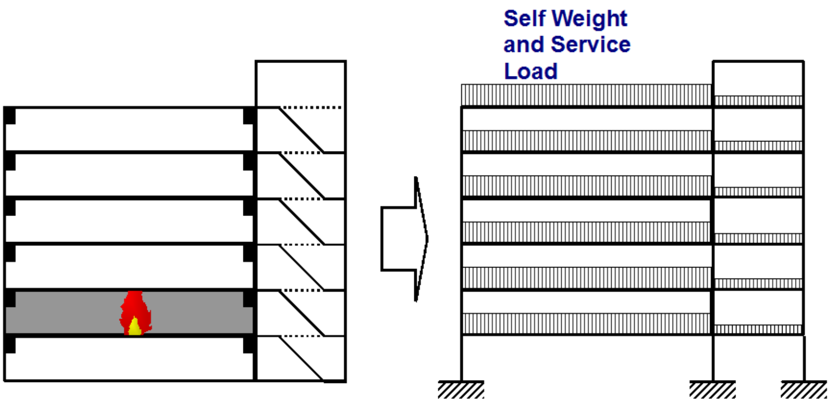
- Fire Resistance
  - prevention of collapse by a fire inside of the building
- Evacuation Safety
  - provision of escape route(s) to a place of safety



Harada et al., 3rd PBC&FSD, June 2000

Evaluation methods of Fire Resistance

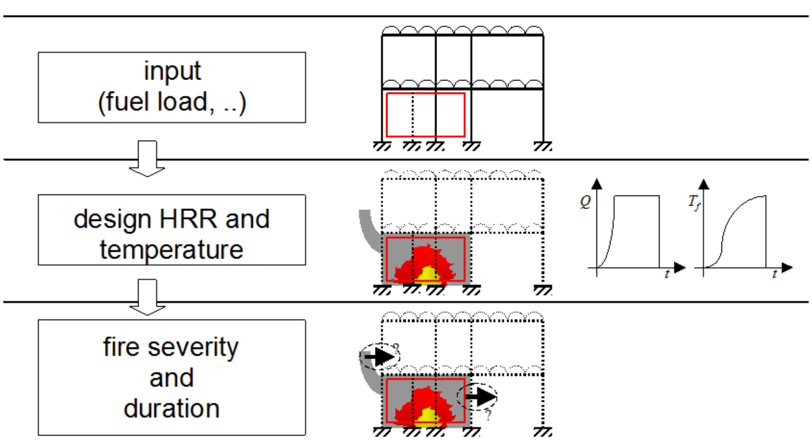
- Fire load and structural load



Harada et al., 3rd PBC&FSD, June 2000

Evaluation methods of Fire Resistance

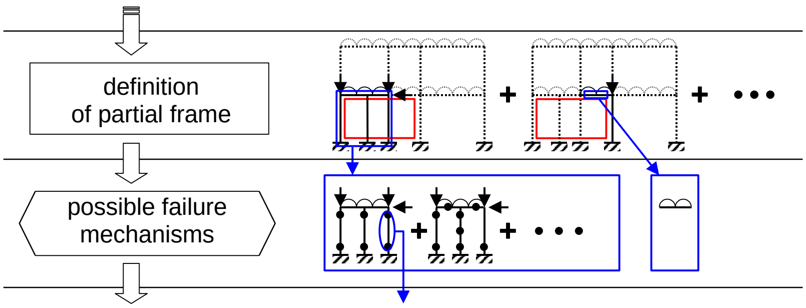
- Calculation of fire action



Harada et al., 3rd PBC&FSD, June 2000

Evaluation methods of Fire Resistance

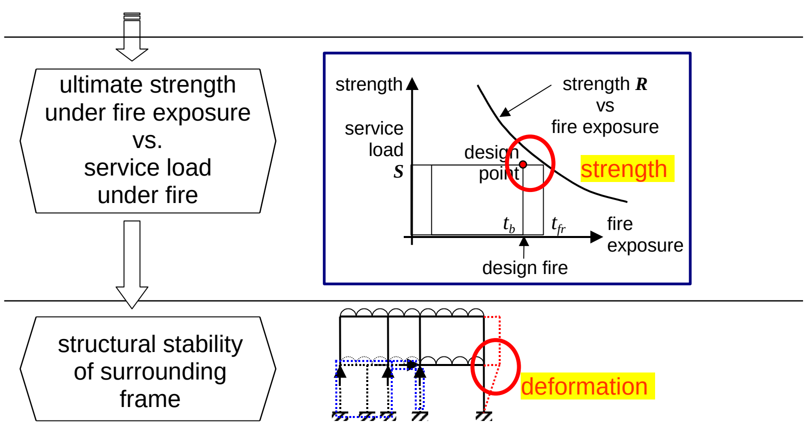
- Calculation of structural response



Harada et al., 3rd PBC&FSD, June 2000

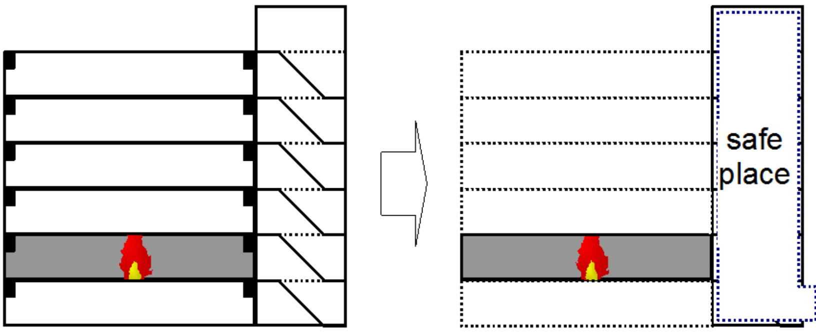
Evaluation methods of Fire Resistance

- Calculation of fire action



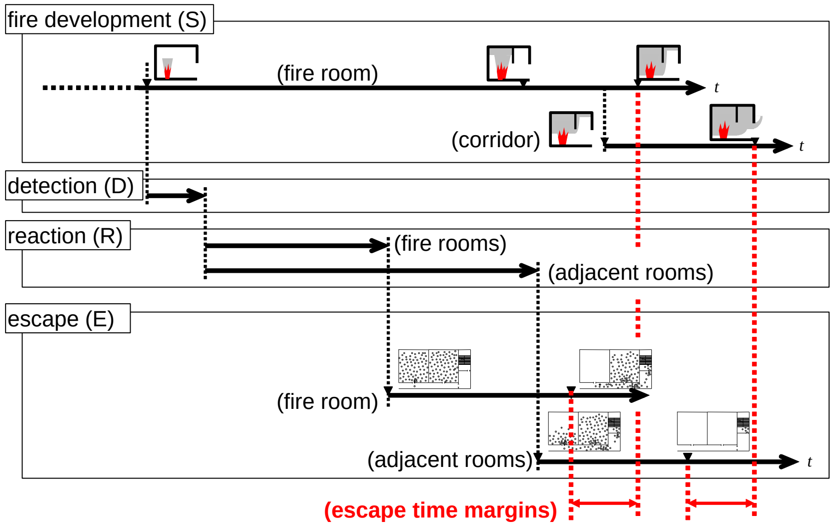
Harada et al., 3rd PBC&FSD, June 2000

Evaluation Methods of Floor Evacuation



Harada et al., 3rd PBC&FSD, June 2000

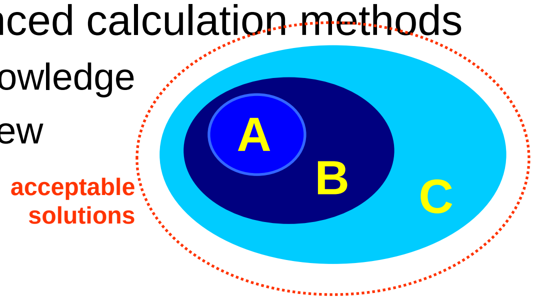
Evaluation Methods of Floor Evacuation



Harada et al., 3rd PBC&FSD, June 2000

Evaluation Methods

- route A – prescriptions
- route B – simple calculation method
  - prescribed method
  - review by building officials only
- route C – advanced calculation methods
  - professional knowledge
  - with expert review



Harada et al., 3rd PBC&FSD, June 2000

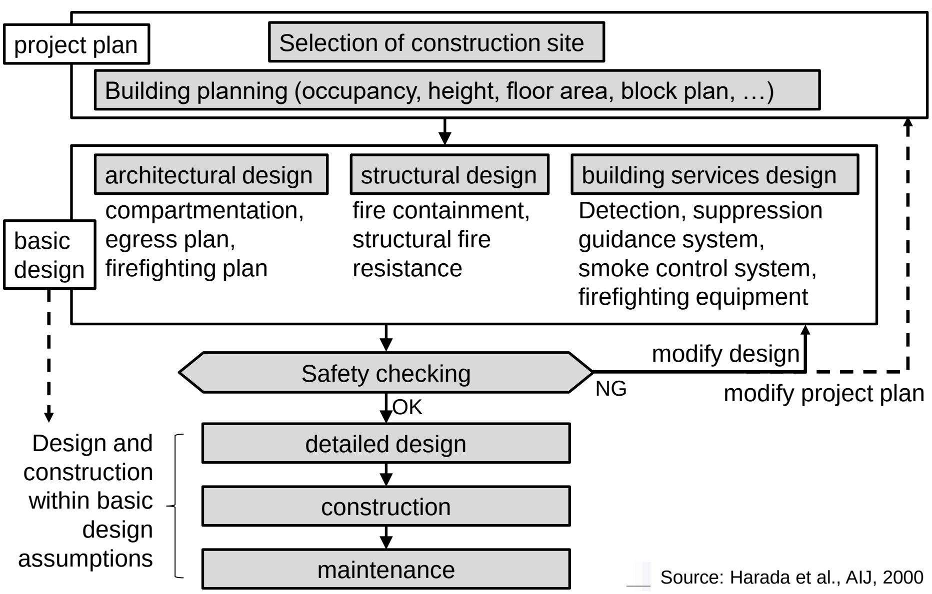
Special Features in Japan

- Calculation method has been *included* in regulation document (MLIT's notification), not in standards.
  - Notification 1433(2000) fire resistance,
  - Notification 1441(2000) floor evacuation
  - Notification 1442(2000) total building evacuation

Changes after 2000

- Application of route B method has been expanded to relatively small buildings, including renovation project.
  - Number and width of stairs are rationalized.
  - Over capacity of smoke venting system are rationalized.
- Evaluation process has been simplified.
  - Review period can be prospected.

FSE in Building Design Process



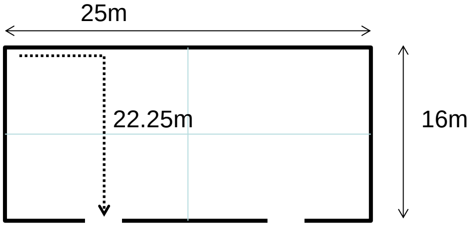
Source: Harada et al., AIJ, 2000

Use of Design Calculations

- Comparison between trial designs
  - Trial design changes everyday
  - Fire calculation must be quick to support decision making in design. Spreadsheet, hand calculation, mental calculation are desirable.
- Conservative calculations are preferred.
  - Do not have to calculate precisely during design process.
  - Detailed design process follows after FSE evaluations. *Large* margin of safety is needed.

Example - room evacuation

- Building parameters
  - Floor area: A_r=400 m^2 (25m x 16m)
  - Ceiling height: H=2.5 m
  - Exits: W=1.2 x (two exits)
  - Walking distance: L=16+25/4=22.25m



Example - room evacuation

- Fire and other parameters
  - Fire source: Q=0.09 t^2 kW
  - Detectors and sprinklers are installed, but the effect was not considered.
  - Smoke venting is mandatory in prescriptive design, but the exclusion is discussed.

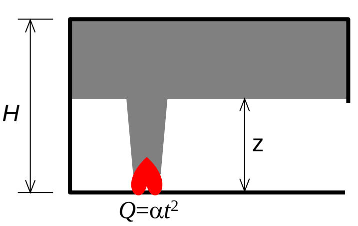
Example - room evacuation

- Calculation of smoke filling time
  - Smoke layer height at time t

$$z(t) = \frac{1}{\left(\frac{0.076}{\rho_s} \frac{\alpha^{1/3}}{A_r} \frac{2}{5} t^{\frac{5}{3}} + \frac{1}{H^{2/3}} \right)^{3/2}}$$

  - Time to specific smoke layer height

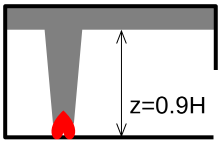
$$t(z) = \left\{ \frac{\rho_s}{0.076} \frac{A_r}{\alpha^{1/3}} \frac{5}{2} \left(\frac{1}{z^{2/3}} - \frac{1}{H^{2/3}} \right) \right\}^{\frac{3}{5}}$$



Example - room evacuation

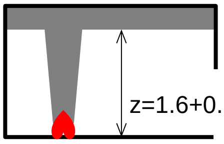
- Time to smoke spread (z=0.9H)

$$t(0.9H)=\left\{\frac{\rho_s}{0.076}\frac{A_r}{\alpha^{1/3}}\frac{5}{2}\left(\frac{1}{(0.9H)^{2/3}}-\frac{1}{H^{2/3}}\right)\right\}^{\frac{3}{5}}=69\,\mathrm{s}$$



- Time to smoke filling (z=1.6+0.1H)

$$t(1.6+0.1H)=\left\{\frac{\rho_s}{0.076}\frac{A_r}{\alpha^{1/3}}\frac{5}{2}\left(\frac{1}{(1.6+0.1H)^{2/3}}-\frac{1}{H^{2/3}}\right)\right\}^{\frac{3}{5}}=135\,\mathrm{s}$$



Example - room evacuation

- Evacuation time
  - Start time:

$$t_{start}=\max(t_{alarm},t_{smoke})=69\,\mathrm{s}$$

  - Walking time

$$t_{walk}=L/v=22.25/1.0=22\,\mathrm{s}$$

  - Queuing time

$$t_{queue}=\frac{pA_r}{1.5W}=\frac{0.25\times 400}{1.5\times(1.2\times 2)}=28\,\mathrm{s}$$

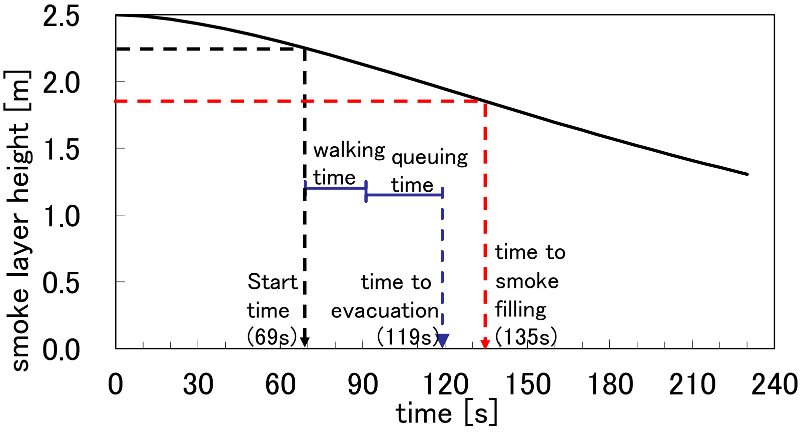
  - Time to room evacuation

Smoke filling time

$$t_{evac}=t_{start}+t_{walk}+t_{queue}=69+22+28=119\,\mathrm{s}<135\,\mathrm{s}$$

Example - room evacuation

- Graphical presentation



Summary- needs for accepted design calculation methods

- Accepted methods
  - Accept*ed* methods are necessary to increase the application of performance-based designs especially to relatively small buildings.
  - Accept*able* methods need to be verified and validated. Procedure is need to be developed. In many real projects, time is not enough to make validation study.

Merits

- Quick calculation
  - Hand or spreadsheet calculation will be obtained quickly.
  - Effective for comparison between trial designs.
  - Easy to modify input parameters for better solutions.
- Educational merit
  - Provide new practitioners with chance to think over fire phenomena and factors for fire safety

Demerits

- Accuracy:
  - Hand or spreadsheet calculation will normally result in conservative results.
  - Not very effective for cost cutting design.
  - However, this feature could be a merit if sensitivity analysis can be omitted and to search for better solutions quickly.

Handbook on Design Calculation Methods of Fire Behavior

- Being developed by a WG in Architectural Inst. of Japan (AIJ)
- Leader: Dr. Shigeru Yamada, Fujita co.
- Members:
  - 3 from academia
  - 1 from national research inst.
  - 8 from private companies including general construction companies, fire engineering consultant offices

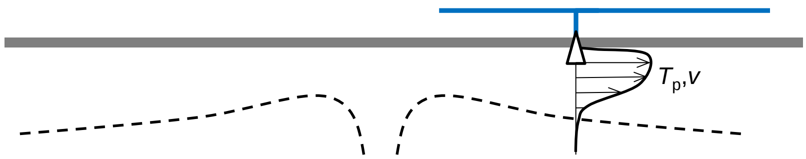
Handbook on Design Calculation Methods of Fire Behavior

- Draft contents
  - 1. combustion and fire load
  - 2. flame height
  - 3. fire plume
  - 4. vent flow
  - 5. heat transfer
  - 6. fully-developed compartment fire
  - 7. flame ejected from window
  - 8. smoke movement and control
  - 9. egress movements

Handbook on Design Calculation Methods of Fire Behavior

- sprinkler activation time
  - RTI=67 $m^{1/2}/s^{1/2}$, v =1.52 m/s,
  - T_p=105°C(221°F), $T_{h,act}$ =72°C (162°F)

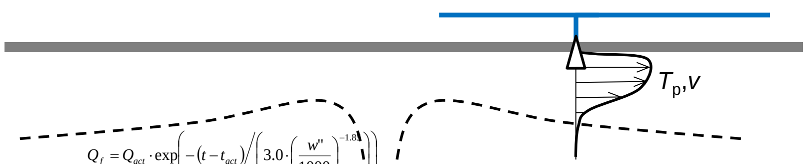
$$t_{act} = \frac{\mathrm{RTI}}{\sqrt{v}} \cdot \ln\left(\frac{T_p - T_0}{T_p - T_{h,act}}\right) = \frac{67}{\sqrt{1.52}} \cdot \ln\left(\frac{105-10}{105-72}\right) \approx 36.1 \text{ sec.}$$



Source: Alpert, R. L, Fire Technology, 1972

Handbook on Design Calculation Methods of Fire Behavior

- reduction of HRR by sprinkler
  - Q_{act}=1125kW, w" = 63 g/(s·m²)



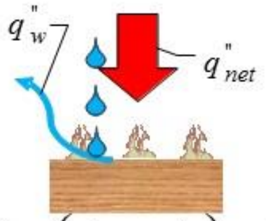
$$Q_f = Q_{act} \cdot \exp\left(-(t - t_{act}) \Big/ \left(3.0 \cdot \left(\frac{w''}{1000}\right)^{-1.85}\right)\right)$$
$$= 1125 \times \exp\left(-(200) \Big/ \left(3.0 \cdot \left(\frac{63}{1000}\right)^{-1.85}\right)\right)$$
$$= 754 \text{ kW}$$

Source: David D. Evans, NISTIR 5254, 1993.8

Handbook on Design Calculation Methods of Fire Behavior

- Control of HRR by sprinkler
  - Q_{max}=1125kW, w" = 63 g/(s·m^2)

$$Q_f^{"} = Q_{\max}^{"} - w" L_w \frac{\Delta H}{L} = 1125 - 63.0 \times 2.26 \times \frac{13.1}{2.26} \approx 300\,\mathrm{kW}$$



$$Q_f^{"} = \left(q_{net}^{"} - q_w^{"}\right) \times \frac{\Delta H}{L}$$

Source: Noaki, M. et al., AIJ, 2014

references

- Kazunori Harada, Naohiro Takeichi, Ai Sekizawa, "Performance Evaluation Methods for Evacuation Safety and for Structural Fire Resistance", 3rd Int. Conf. on Performance – Based Codes and Fire Safety Design Methods, pp. 212-223, June 2000
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- Source: David D. Evans: Sprinkler Fire Suppression Algorithm for HAZARD, NISTIR 5254, 1993.8
- Noaki, M., J. Environmental Eng. In Architecture, 2014, Architectural Institute of Japan (in Japanese)