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Economic Cooperation

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Seismic Retrofit Work of School Buildings

Submitted by: Chinese Taipei

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Seismic Retrofit Work of School Buildings

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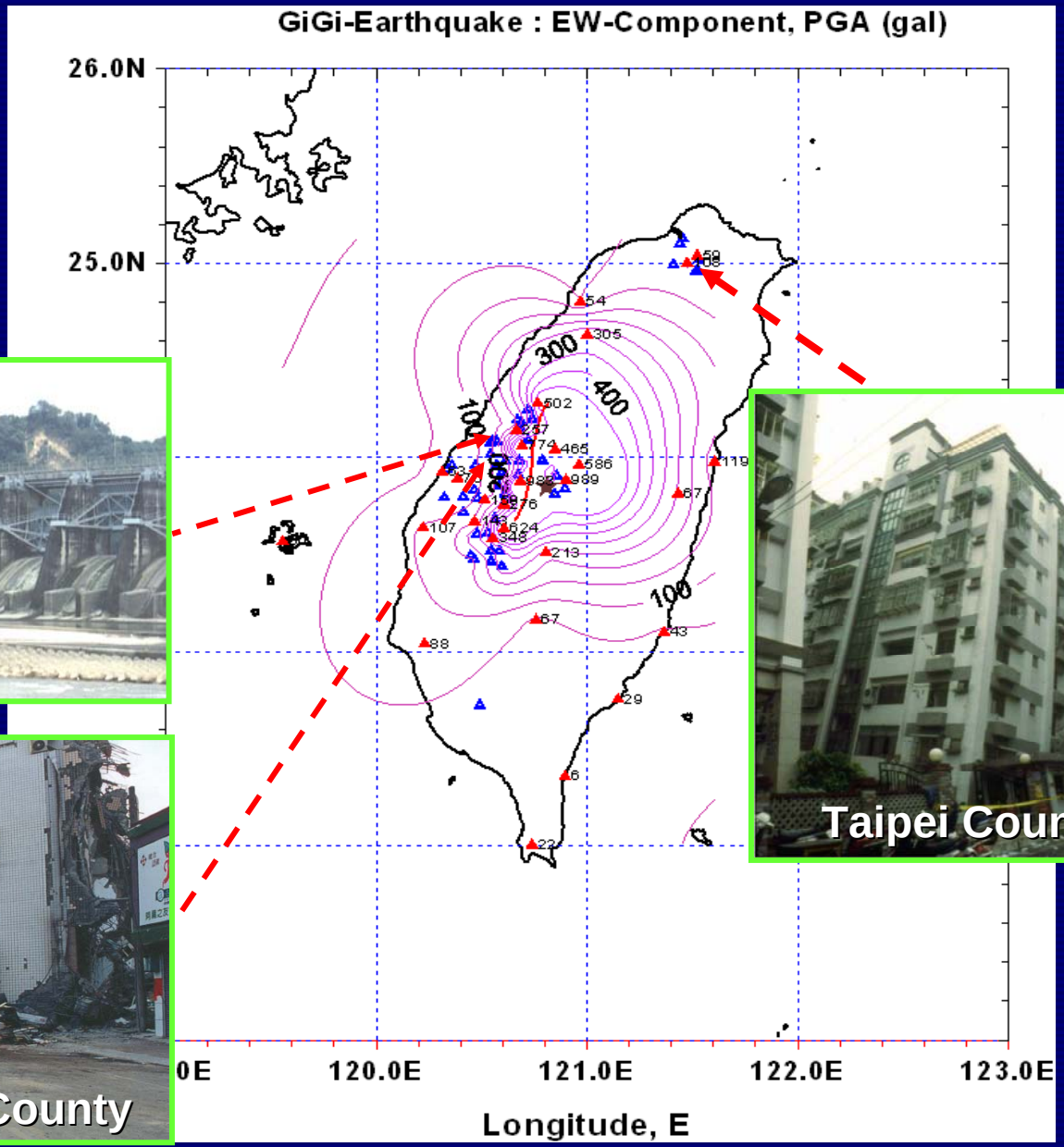
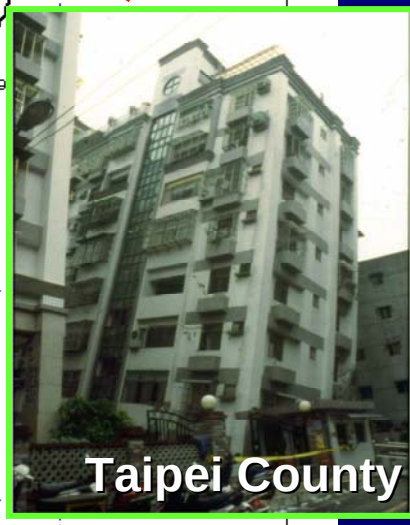
1999 Chi-Chi Earthquake

M_L=7.3
Sept. 21, 1999





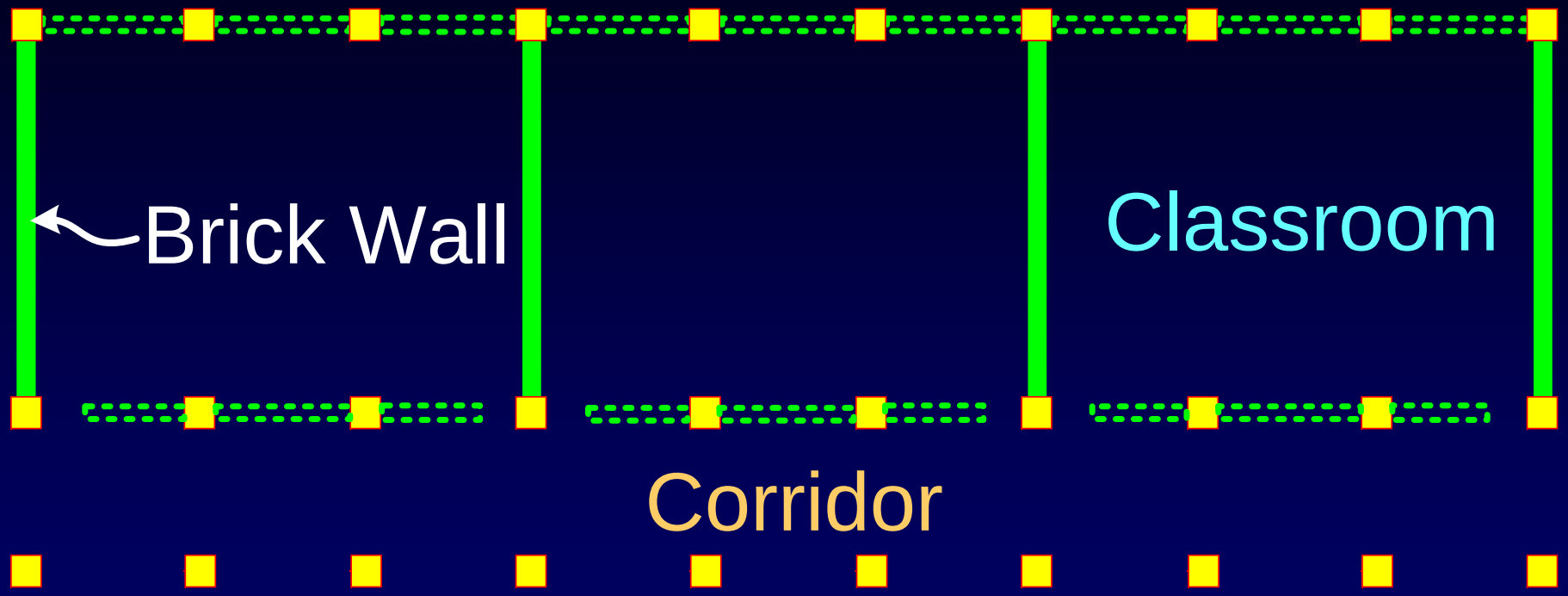
Seismic Deficiency of School Buildings






If earthquake happened at school hours, death toll could have been much more

Floor Plan of Typical School Buildings



Weak Direction

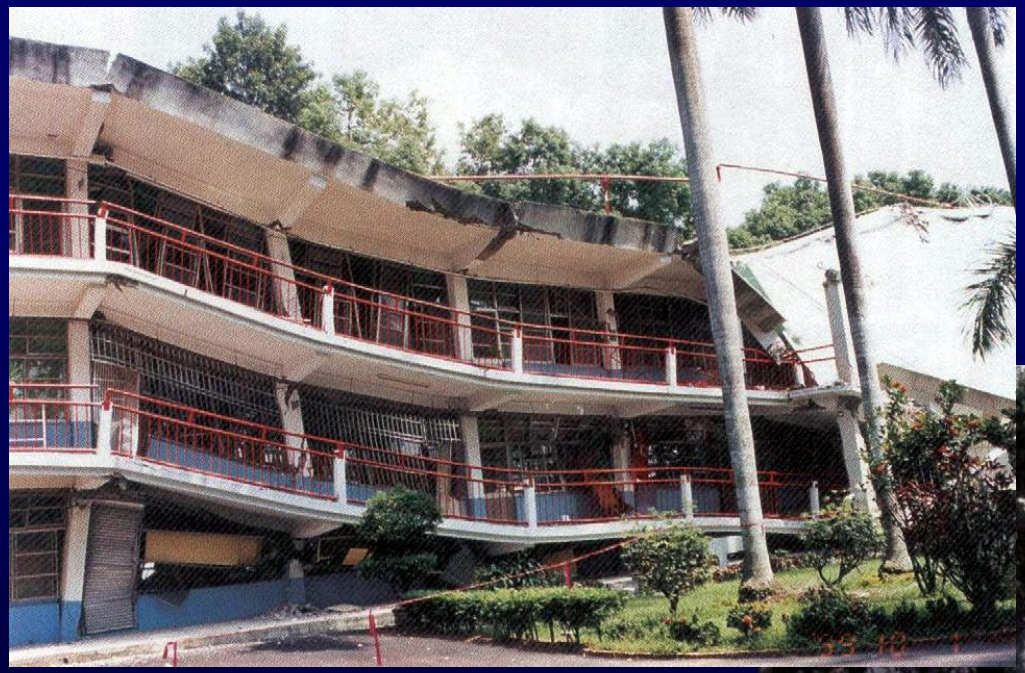
Vulnerable along Corridor Direction

Typical Characteristics of School Buildings

- Most vulnerable category of buildings
- Similar in structural system
- Directivity: vulnerable along the corridor
- First story is most critical
- Strong-beam-weak-column
- Poor Concrete strength

Seismic performance depends on columns and walls along the corridor at first story

Column Failures at First Floors



Non-ductile Detailing for Columns

(a) Widely Spaced Hoops

(b) 90º Hooks for Hoops

(c) Splices within Plastic Zones

Magnitude of the Problem

Number of schools for compulsory education (elementary and junior high schools) is larger than 3,000

Number of school buildings for compulsory education is larger than 15,000

$$\frac{\text{collapse or severe damaged}}{\text{total (Nantou County)}} = \frac{293}{496} \cong \frac{1}{2}$$

Current Actions

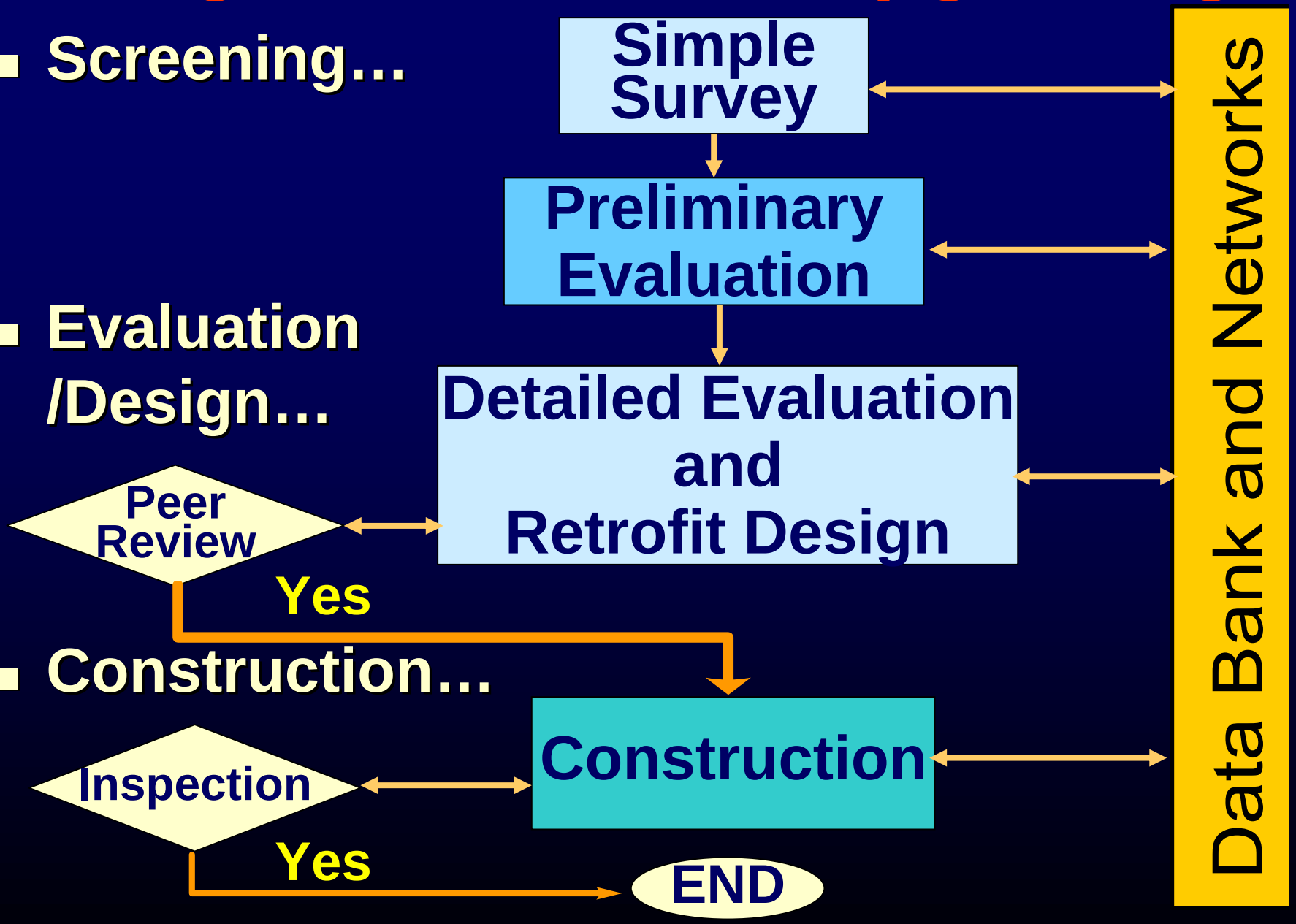
- **Governmental mandate – all essential public buildings are mandatory to go through the process of seismic evaluation and retrofit**
- **Ministry of Education promised to allocate a budget of US $600 millions (NT $20 Billions) in a time span of 5 years**

Strategy for School Upgrading

- Screening and prioritization
- Simple
- Reliable
- Systematic
- Cost-effective

Stages for School Upgrading

- Screening…
- Evaluation /Design…
- Construction…



Stages for School Upgrading

- **Simple Survey** by school administration through internet
- **Preliminary Evaluation** by P.E.'s through filling templates
- **Detailed Evaluation and Retrofit Design** by P.E.'s
  cost effective methods are verified

Auxiliary Measures

- **Detailed Evaluation and Retrofit Design**
  conducted by same P.E.
- **Peer Review**
  for detailed evaluation and retrofit design
- **Inspection**
  for retrofit construction
- **Data Bank and Information Networks**
  for survey, evaluation and retrofit

Preliminary Evaluation

- Templates filled by P.E.
- Capacity-to-demand ratios
- Capacity:
  dimensions of columns and walls
- Demand:
  weight and location of buildings

Preliminary Evaluation

Assumptions

- Failure along corridor
- Dead load 900 kg/m^2
- Compressive strength 160 kg/cm^2
- Yield strength of steel reinforcement 2800 kg/cm^2

Preliminary Evaluation

- **Capacity**: dimensions of columns and walls

  A_{RCC} reinforced concrete columns

  A_{RCW} reinforced concrete walls

  A_{BW4} four-side bounded brick walls

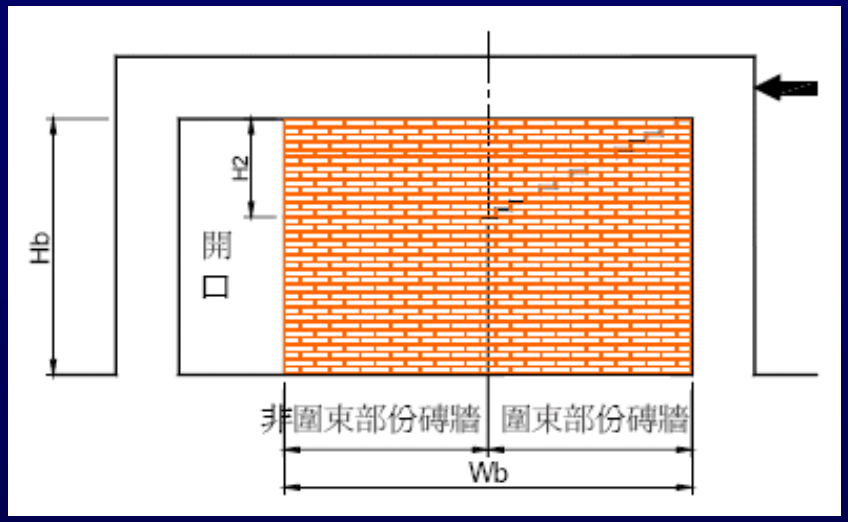
  A_{BW3} three-side bounded brick walls

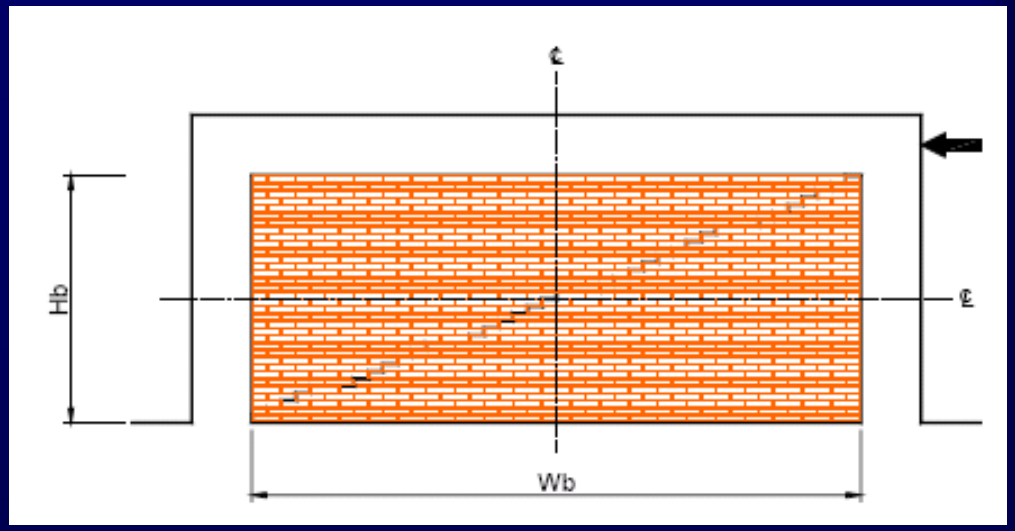
- **Demand**: weight and location of buildings

  A_f floor area above first floor

  Z factor for seismic zones

3-side and 4-side bounded walls





$\tau_{BW4} = 3.0\text{kg/cm}^2$

Shear Capacity

Three-side bounded brick walls $\tau_{BW3} = 1.5\text{kg/cm}^2$

Four-side bounded brick walls $\tau_{BW4} = 3.0\text{kg/cm}^2$

Reinforced-concrete columns $\tau_{RCC} = 15.0\text{kg/cm}^2$

Reinforced-concrete walls $\tau_{RCW} = 24.0\text{kg/cm}^2$

Fundamental Seismic Performance

$$E = \frac{\text{Capacity}}{\text{Demand}} = \frac{0.5A_{BW3} + A_{BW4} + 5A_{RCC} + 8A_{RCW}}{10ZA_f}$$

Modification factor

$$Q = q_1 q_2 q_3 q_4 q_5 q_6$$

- Regularity
- Soft and weak story
- Crack, corrosion and leakage
- Differential settlement
- Redundancy
- Short columns

Seismic Performance Index

$$I_s = EQ = q_1 q_2 q_3 q_4 q_5 q_6 \left(\frac{0.5A_{BW3} + A_{BW4} + 5A_{RCC} + 8A_{RCW}}{10ZA_f} \right)$$

$I_s < 80$ **Seriously damaged or collapsed**
Higher priority for detailed evaluation

$80 \le I_s \le 100$ **Damaged**
Lower priority for detailed evaluation

$I_s > 100$ **Not seriously damaged**
No action taken

Simple Survey

- Simplified from the preliminary evaluation method
- Template filled out by school administrators
- Submitted through internet
- All walls are considered as three-side bounded brick walls

Fundamental Seismic Performance

$$E = \frac{\text{Capacity}}{\text{Demand}} = \frac{0.5A_W + 5A_C}{10ZA_f}$$

Modification Factor

$$Q = q_1 q_2 q_3 q_4 q_5 q_6$$

Seismic Performance Index

$$I_s = EQ = q_1 q_2 q_3 q_4 q_5 q_6 \left(\frac{0.5A_W + 5A_C}{10ZA_f}\right)$$

Simple Survey

$I_s < 80$

Seriously damaged or collapsed
Higher priority for preliminary evaluation

$80 \le I_s \le 100$

Damaged
Lower priority for preliminary evaluation

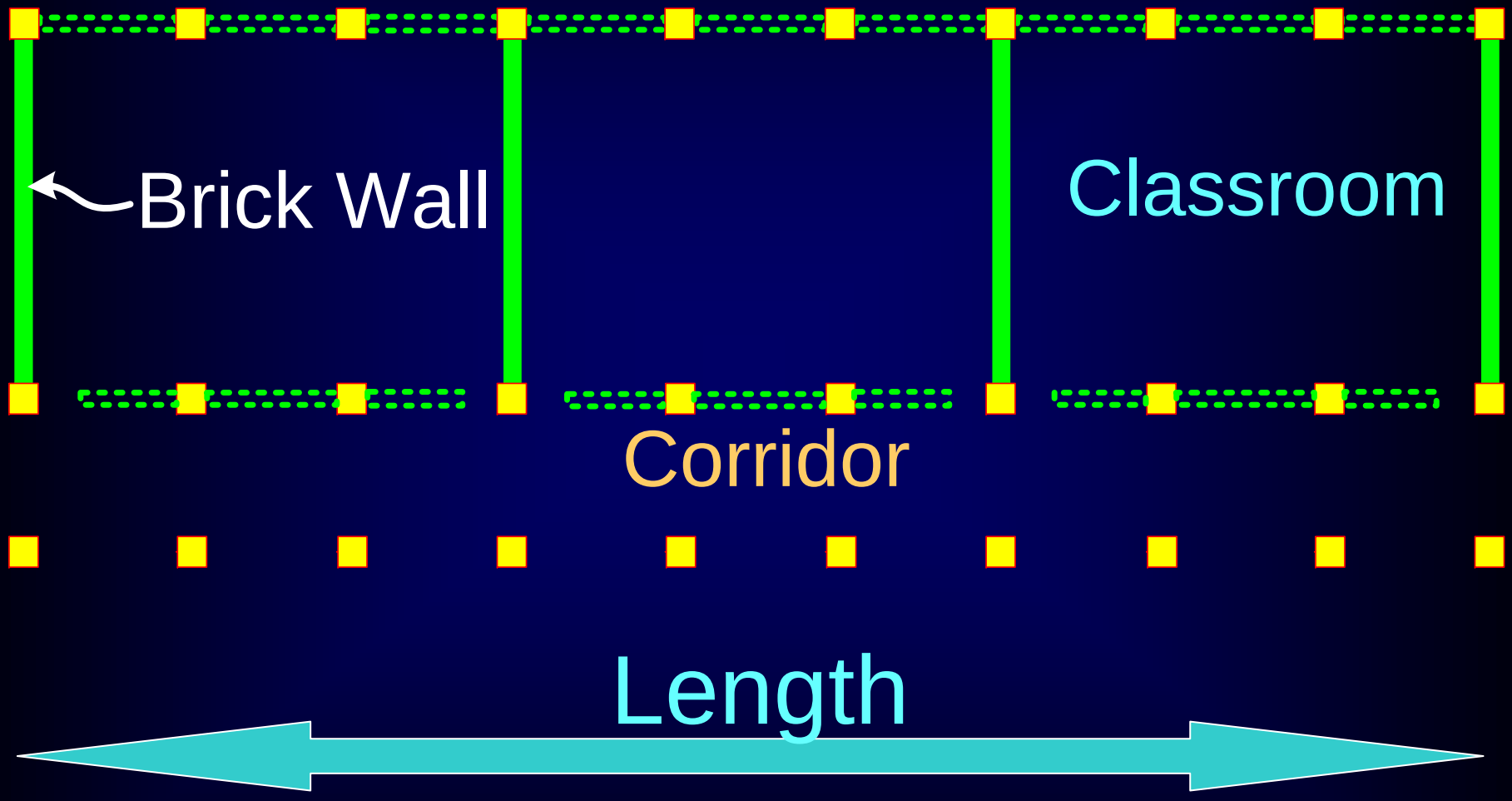
$I_s > 100$

Not seriously damaged
No action taken

Simple Survey

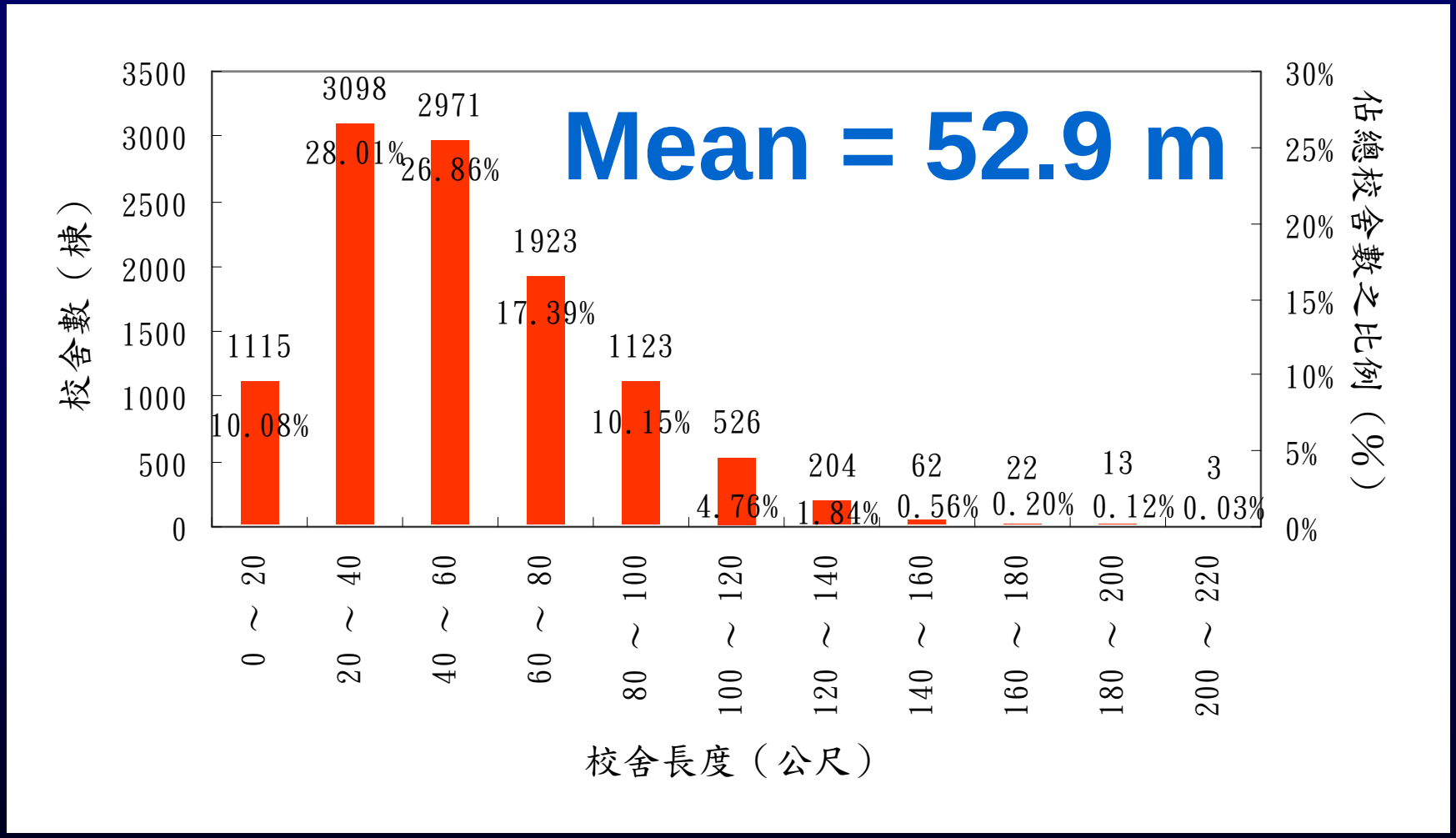
- 3419 out of 3497 schools (97.77%) completed the simple survey
- 11060 out of 12650 buildings' data (87.43%) are valid

Floor Plan of Typical School Buildings



Simple Survey (11060 buildings)

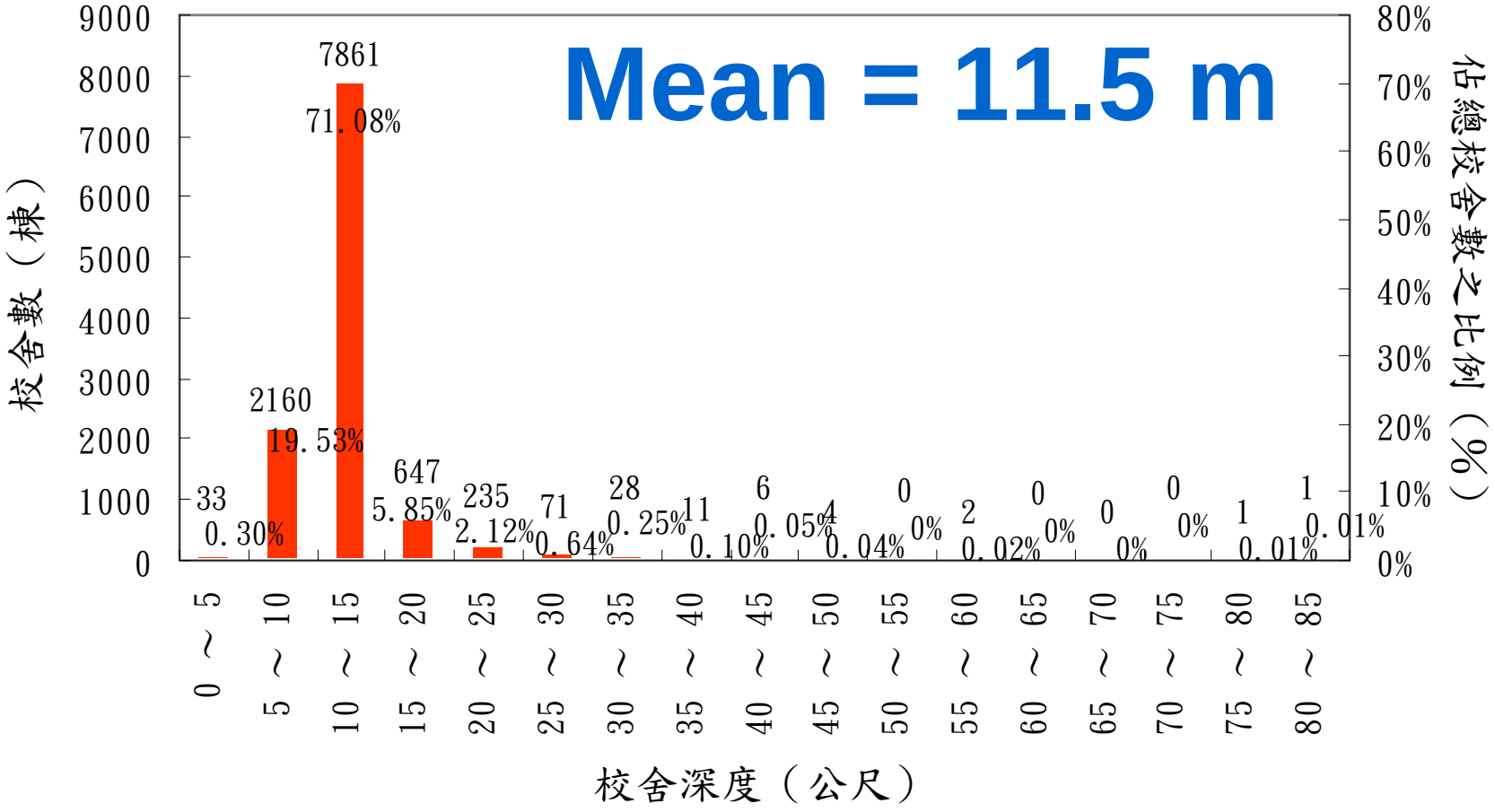
No. of Buildings



Building Length (m)

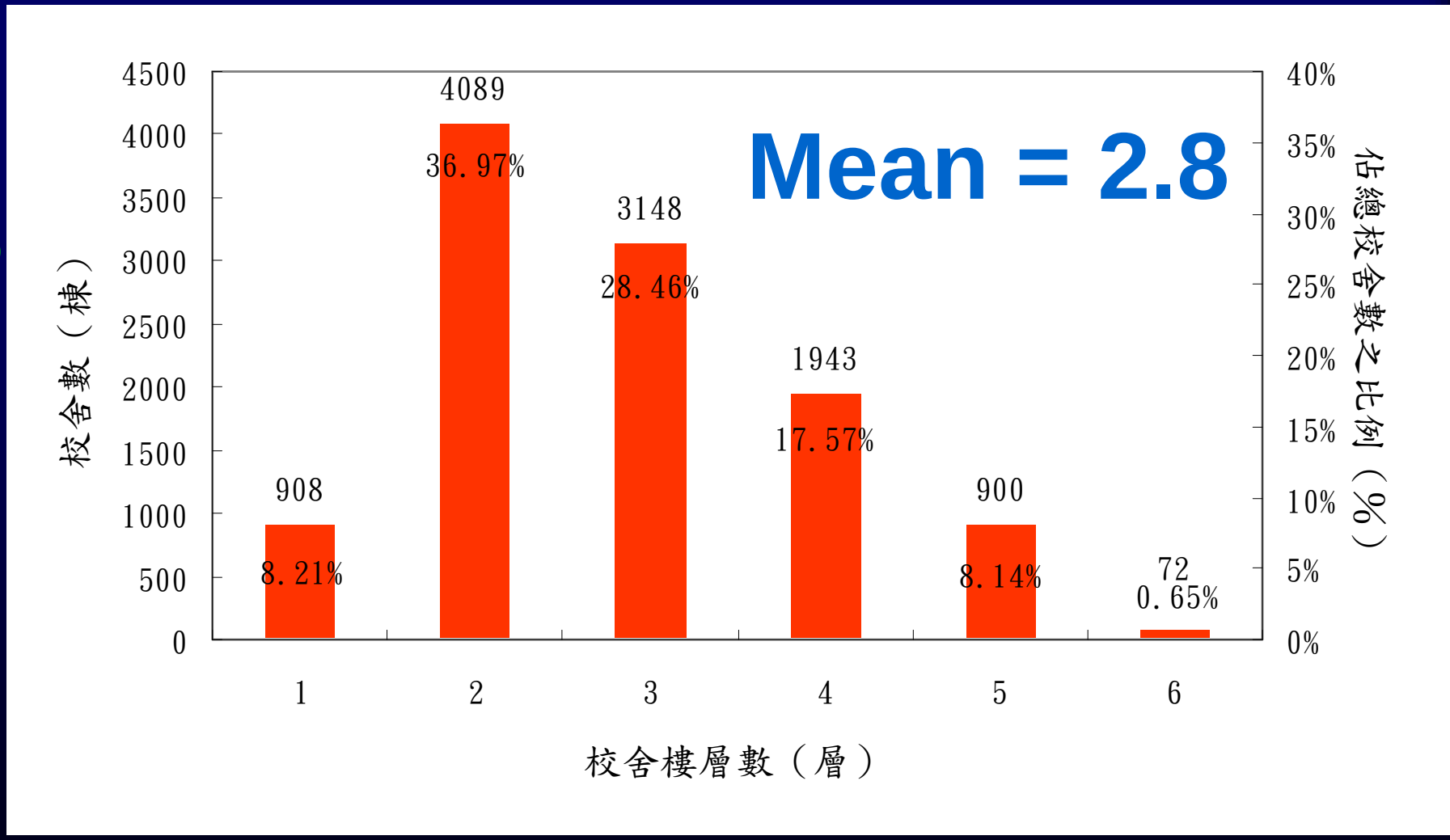
Simple Survey (11060 buildings)

No. of Buildings



Building Depth (m)

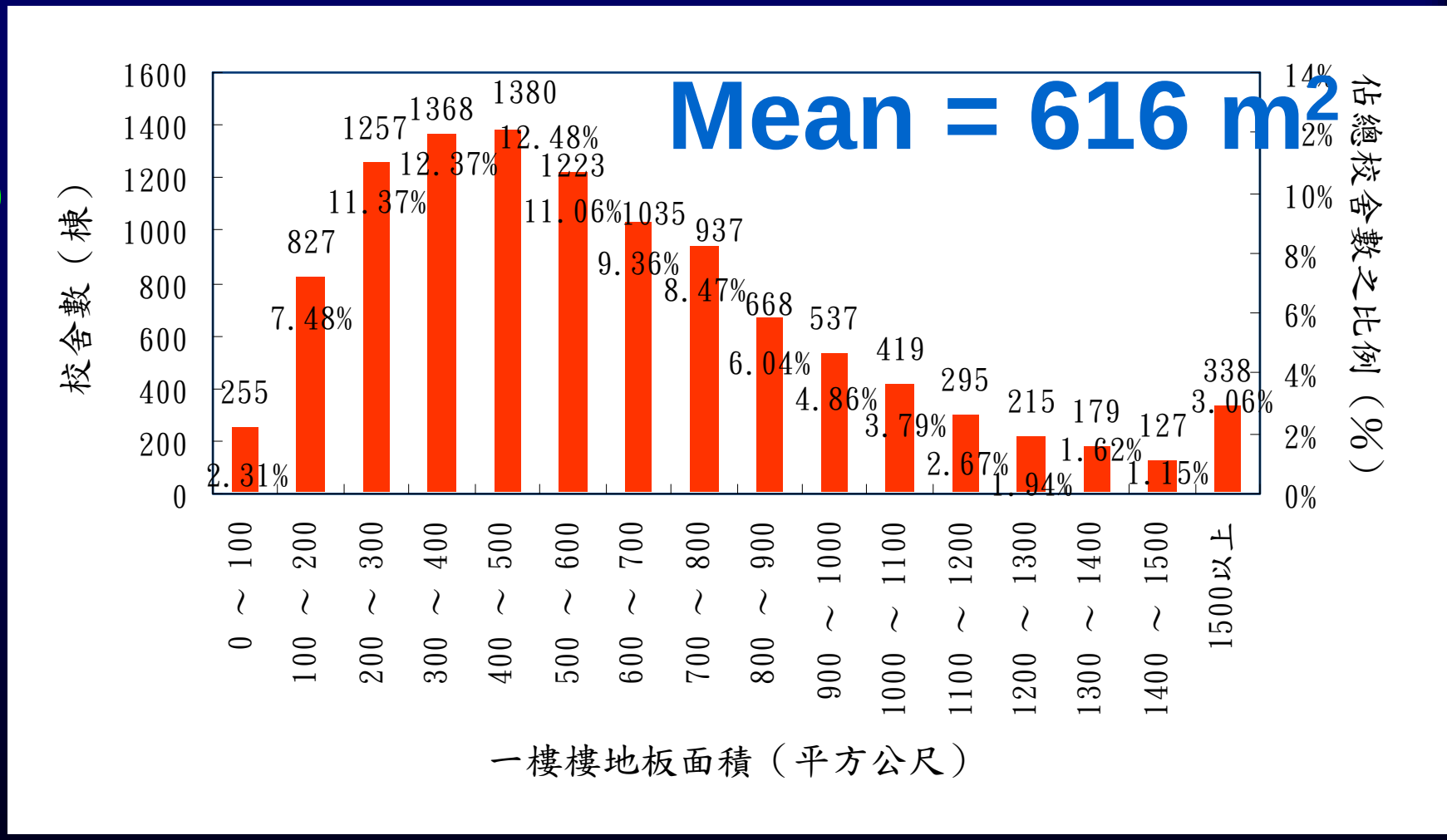
Simple Survey (11060 buildings)



No. of Buildings

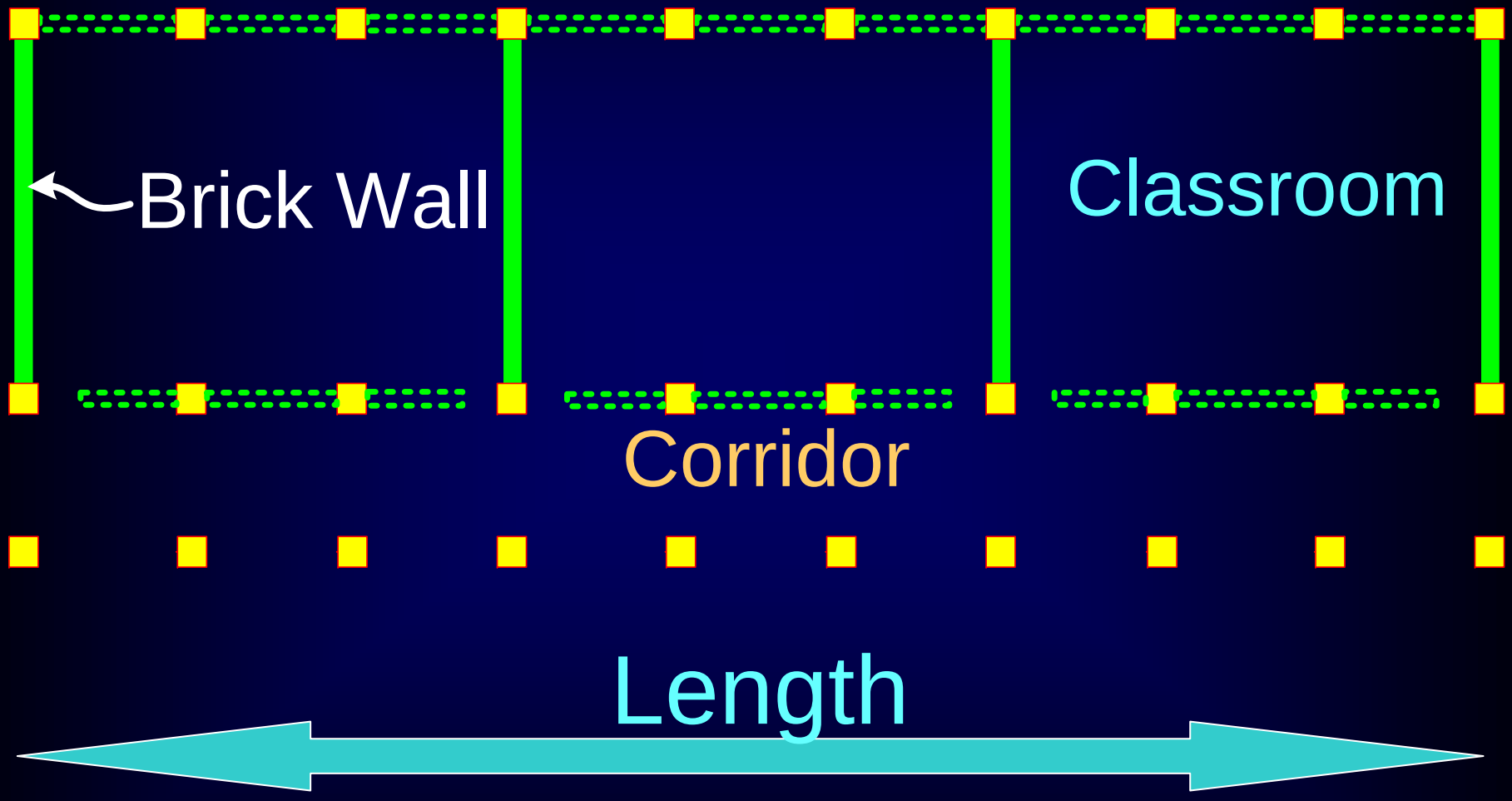
No. of Stories

Simple Survey (11060 buildings)

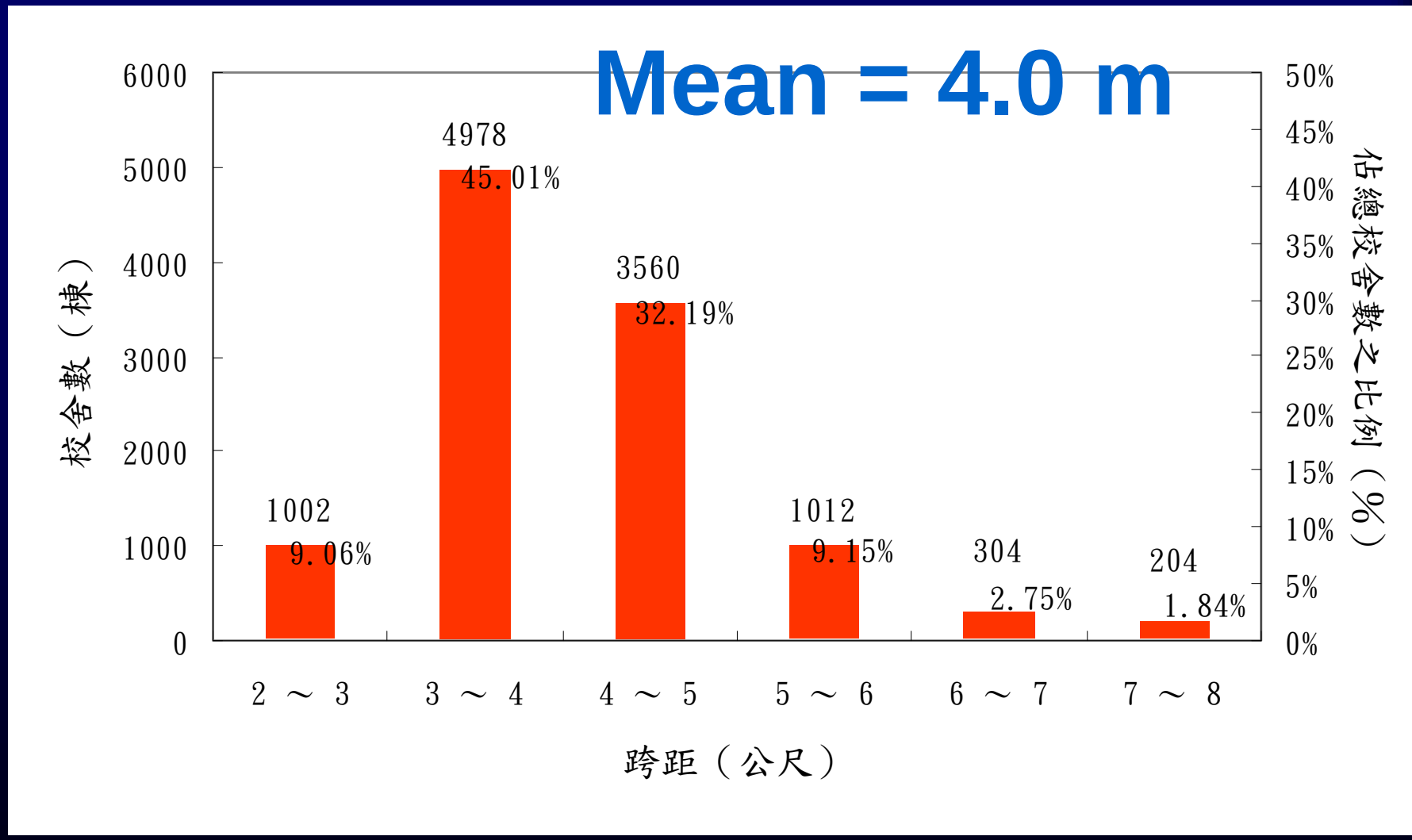


Floor area of 1st floor (m^2)

Floor Plan of Typical School Buildings



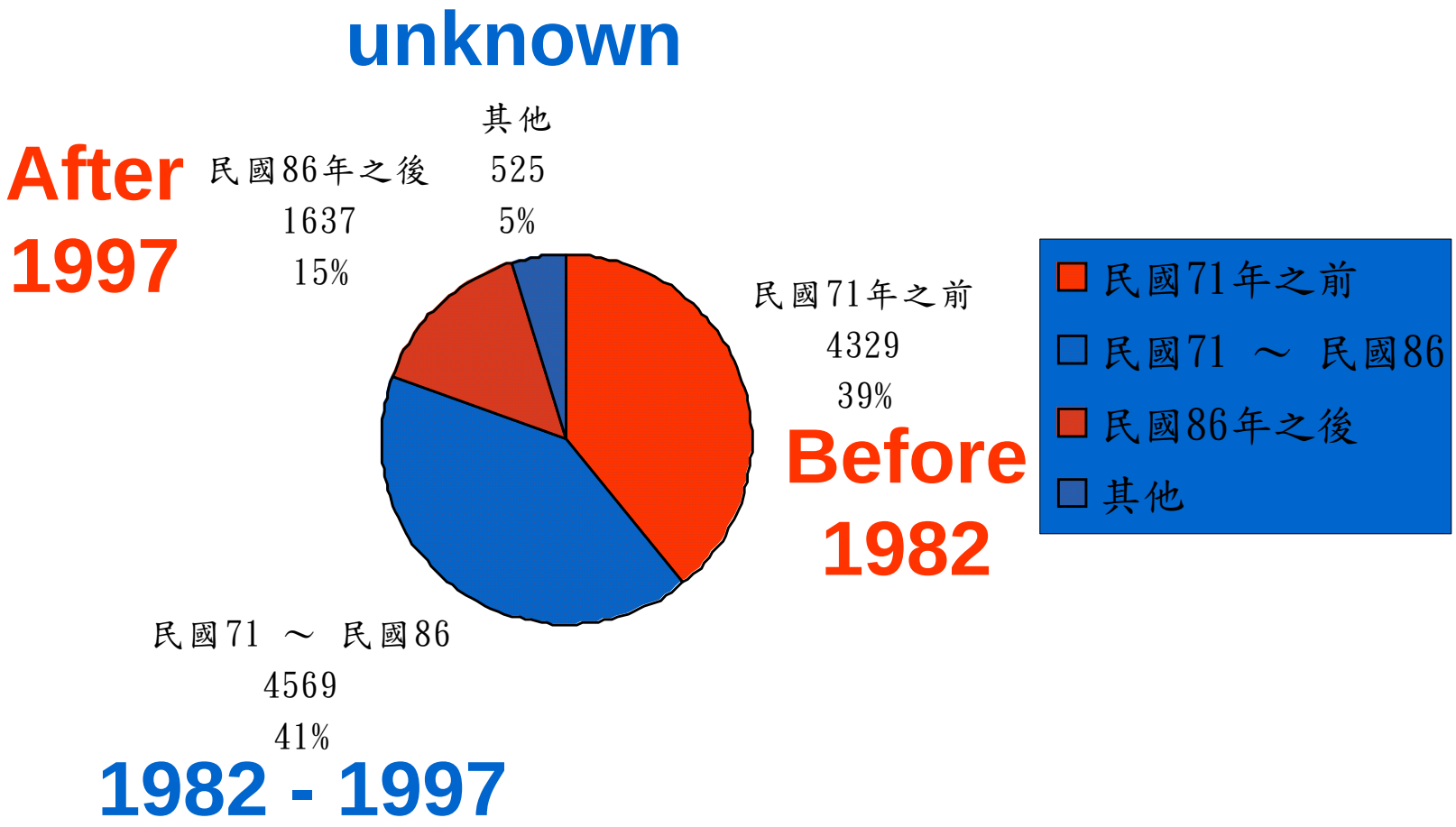
Simple Survey (11060 buildings)



No. of Buildings

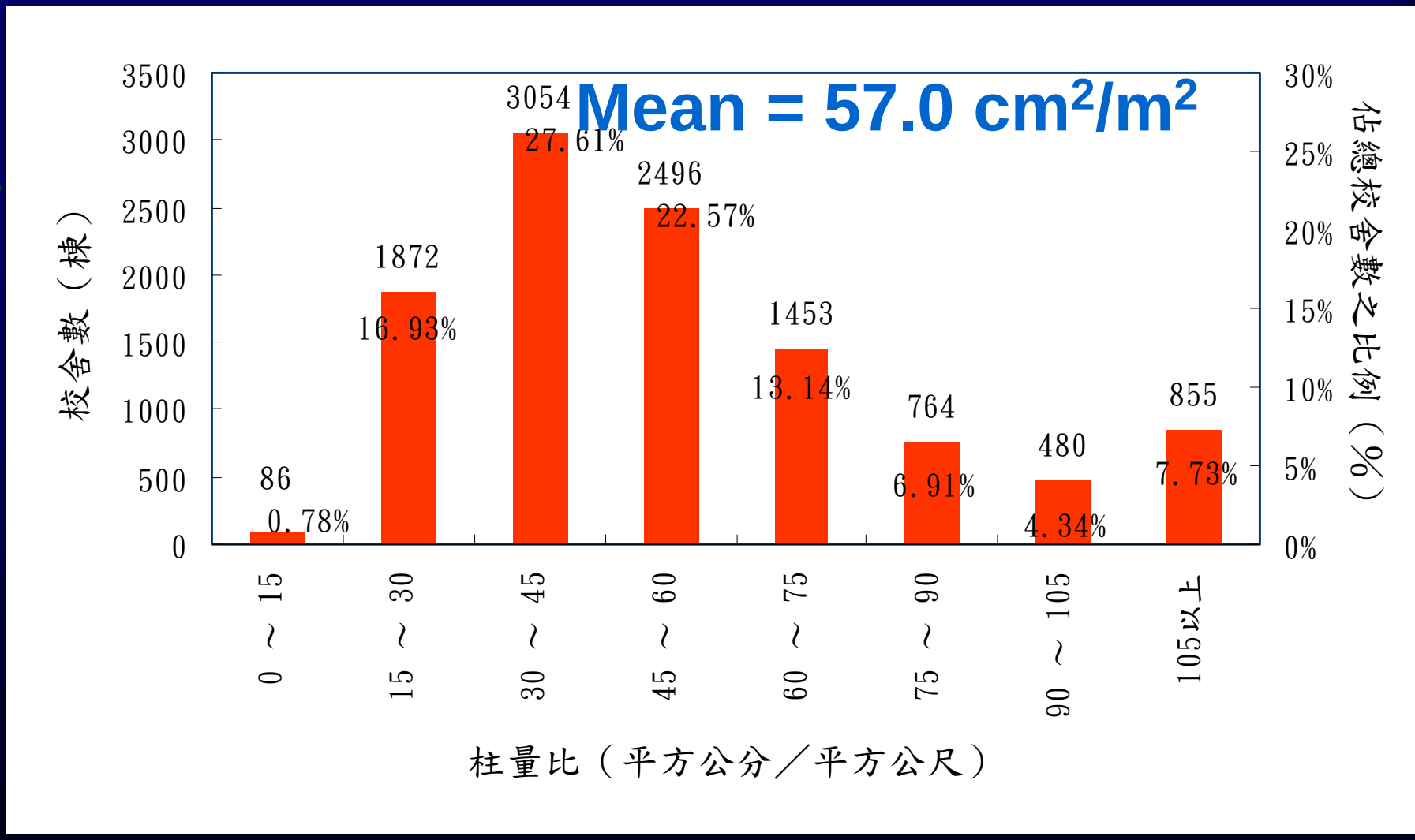
Column Span (m)

Simple Survey (11060 buildings)



Year of Construction (%)

Simple Survey (11060 buildings)

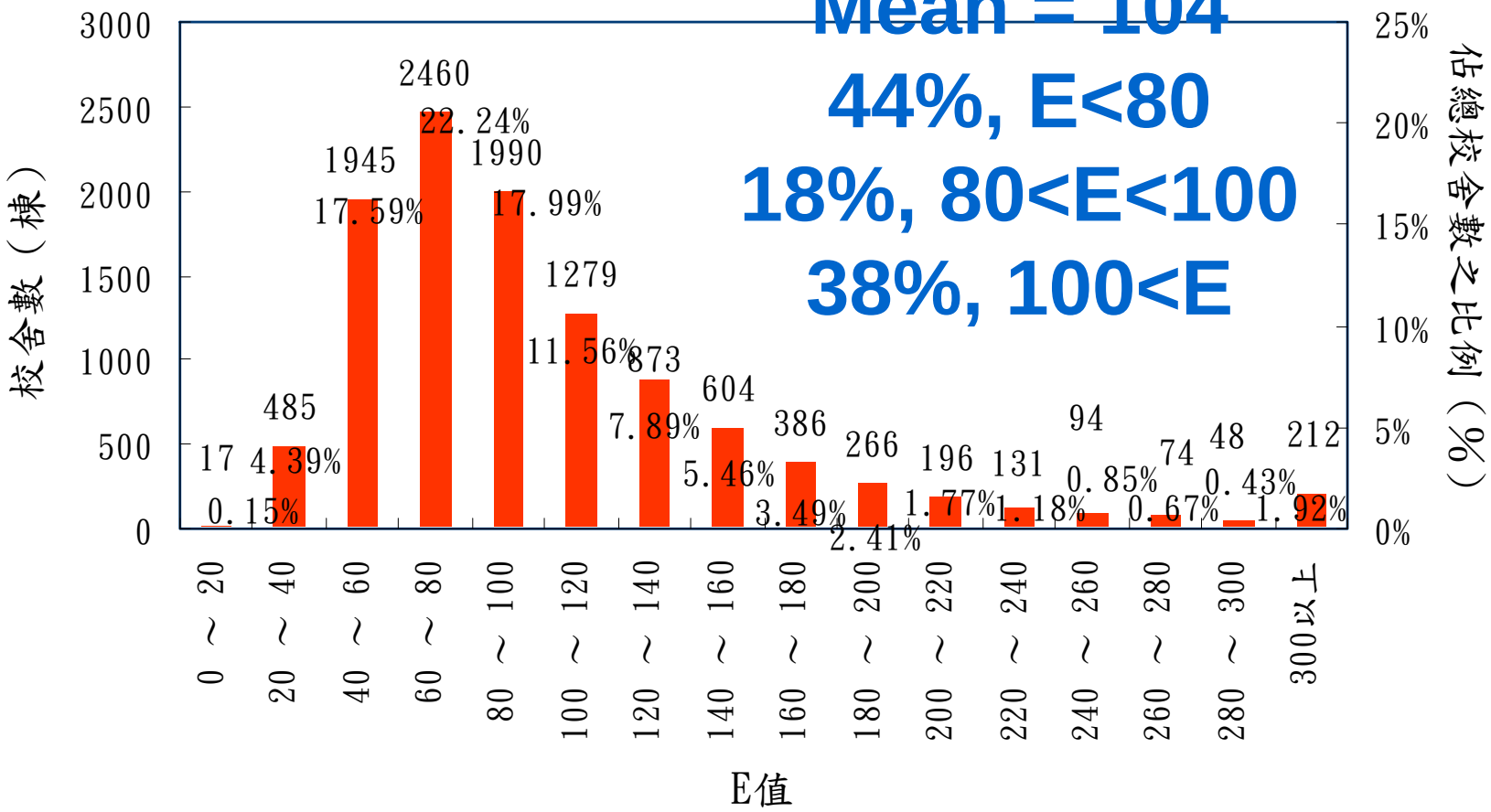


No. of Buildings

Column area / Floor area (cm^2/m^2)

Simple Survey (11060 buildings)

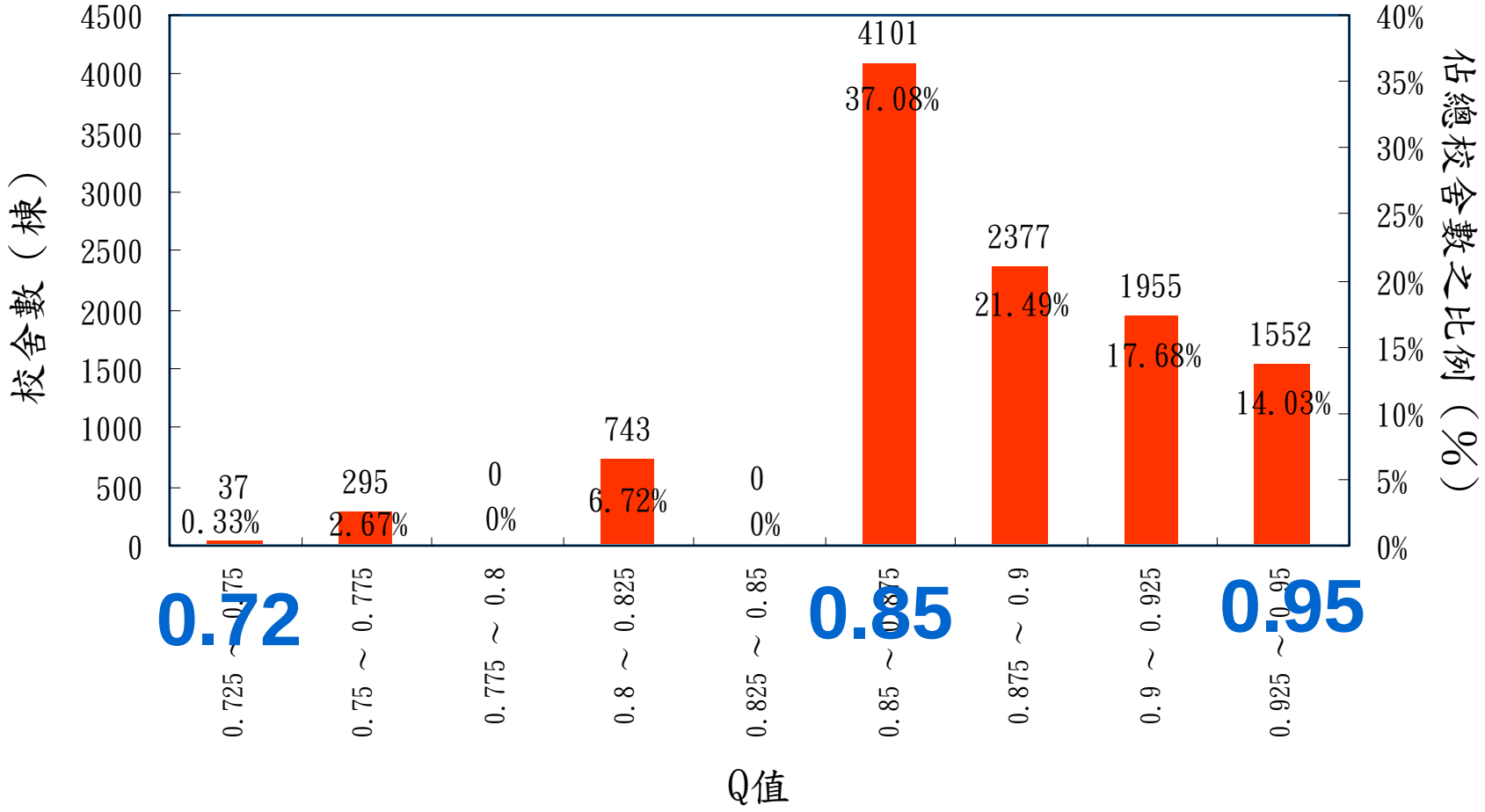
No. of Buildings



Fundamental seismic performance *E*

Simple Survey (11060 buildings)

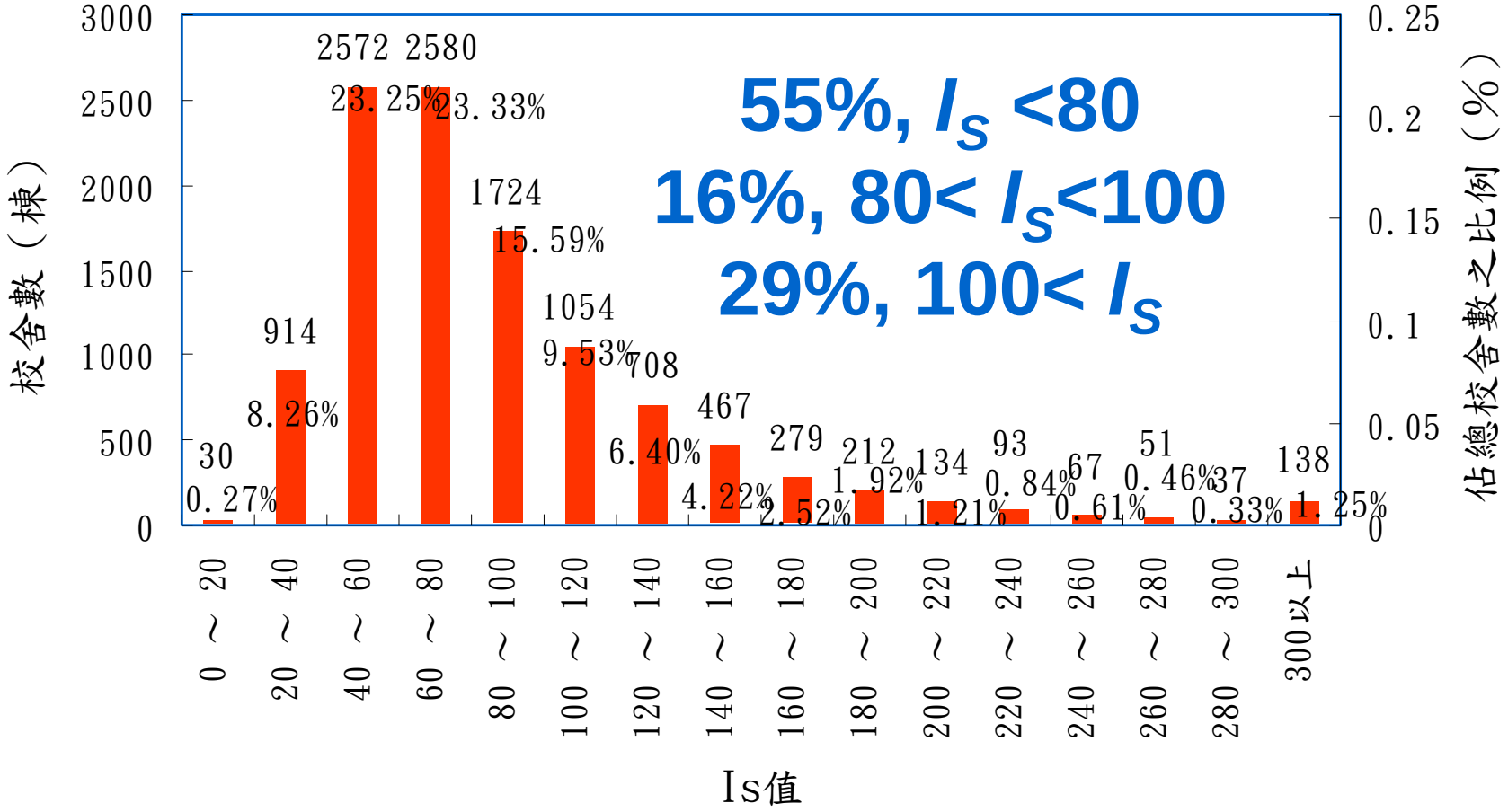
No. of Buildings



Modification factor Q

Simple Survey (11060 buildings)

No. of Buildings



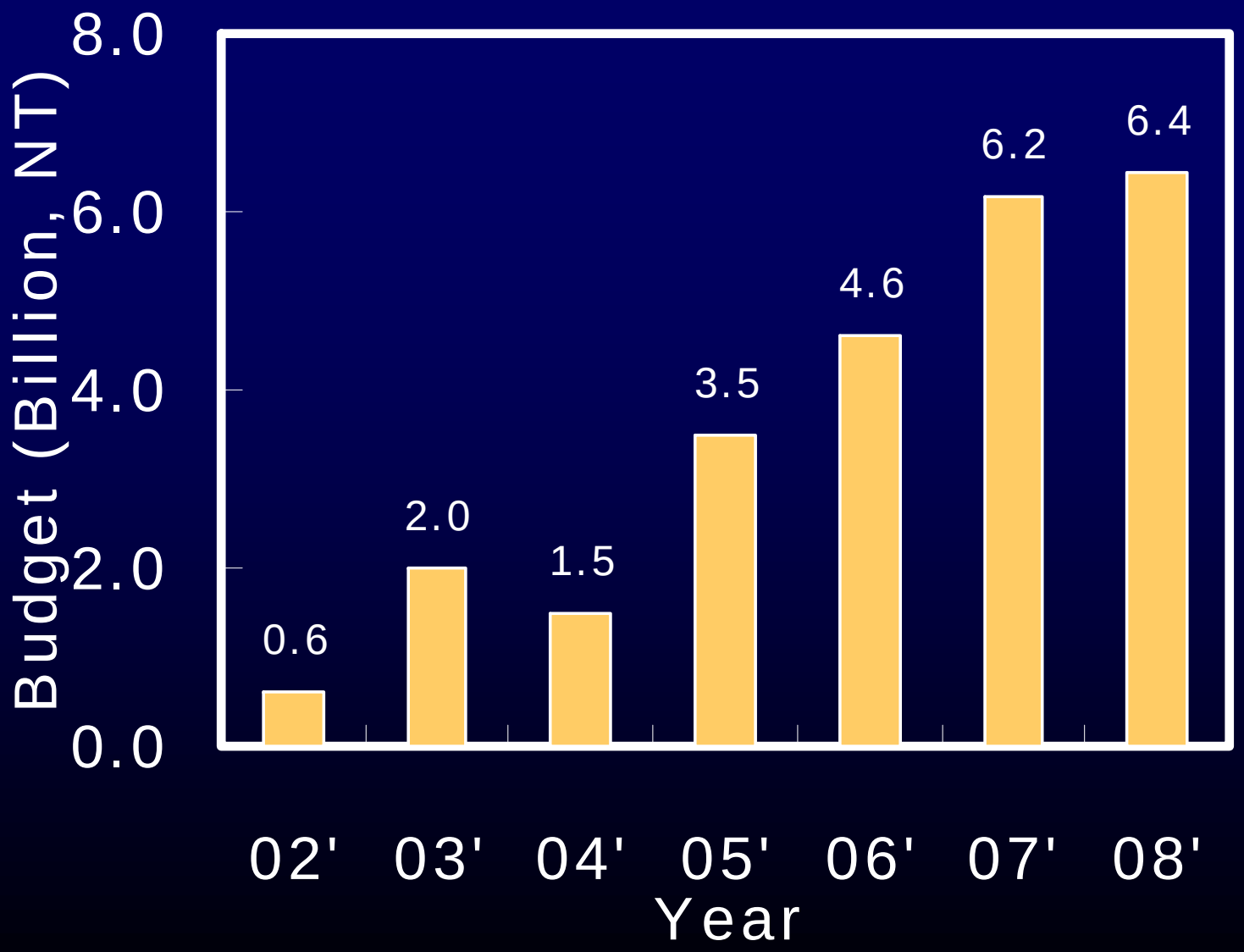
Seismic performance index I_s


8/23/2000 15:14


8/31/2000 14:39

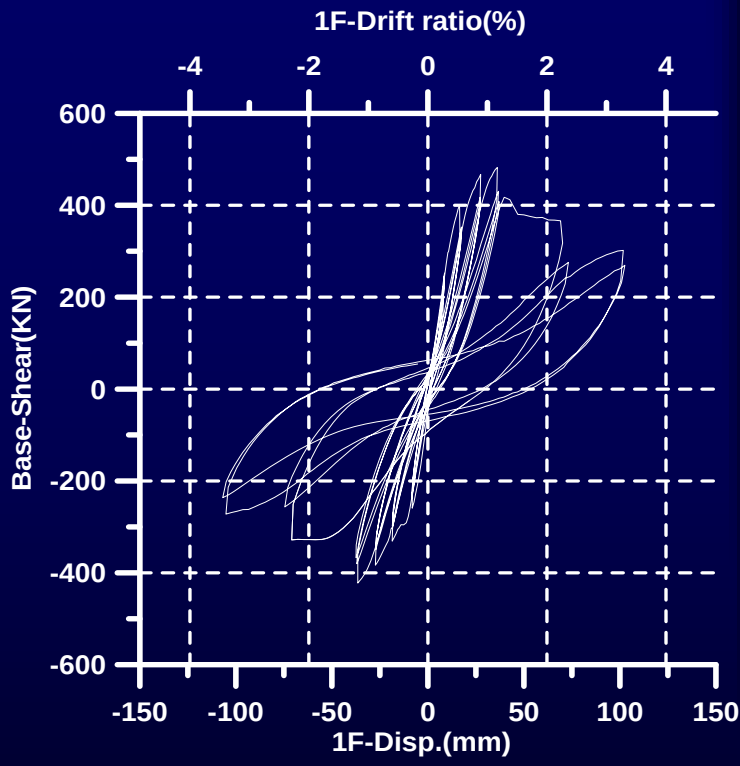

9/21/2000 13:56

Annual Budget for Repair/Reconstruction of School Buildings (Ministry of Education)



Test Setup

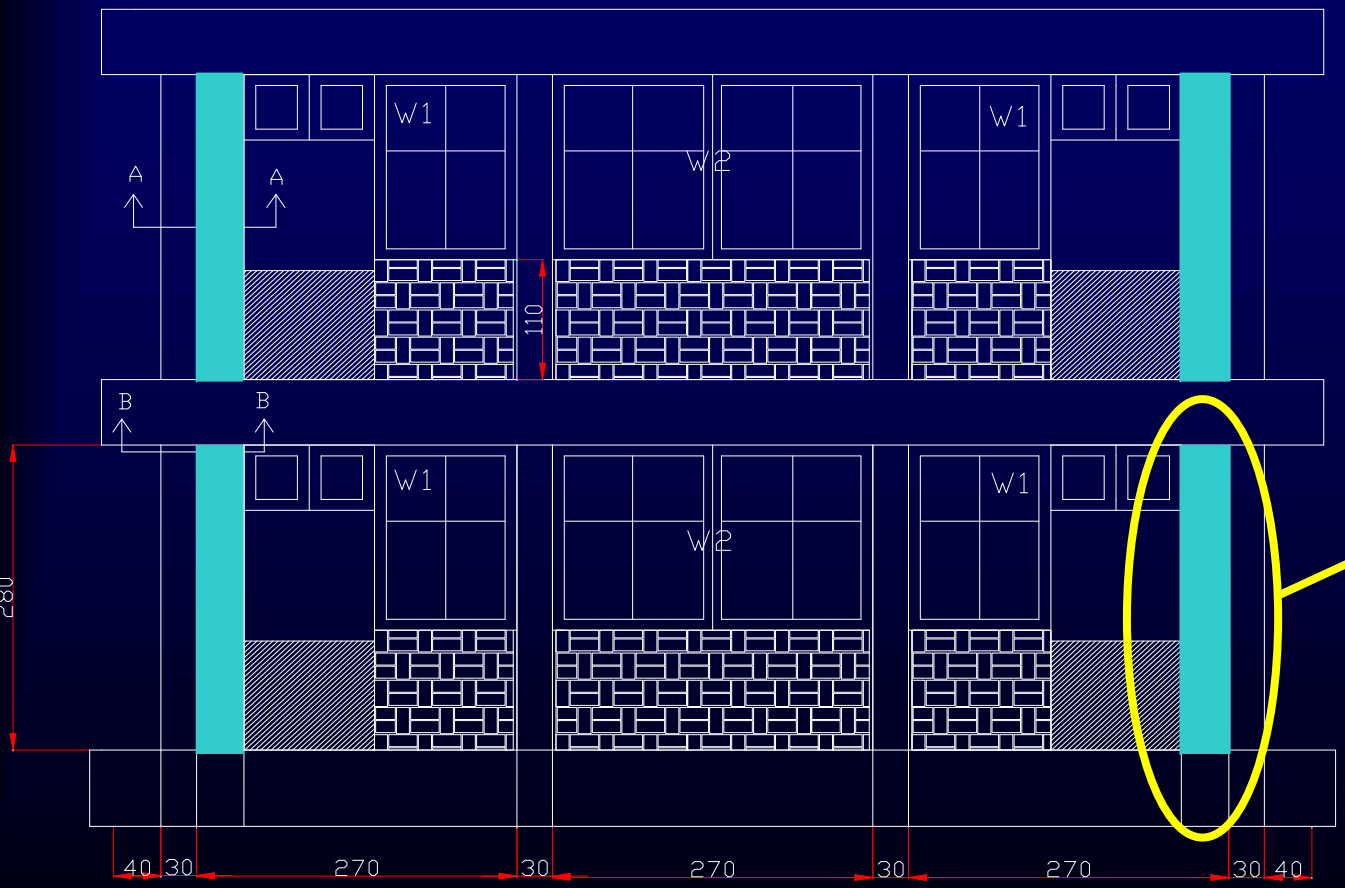
Test Result(1) – Prototype

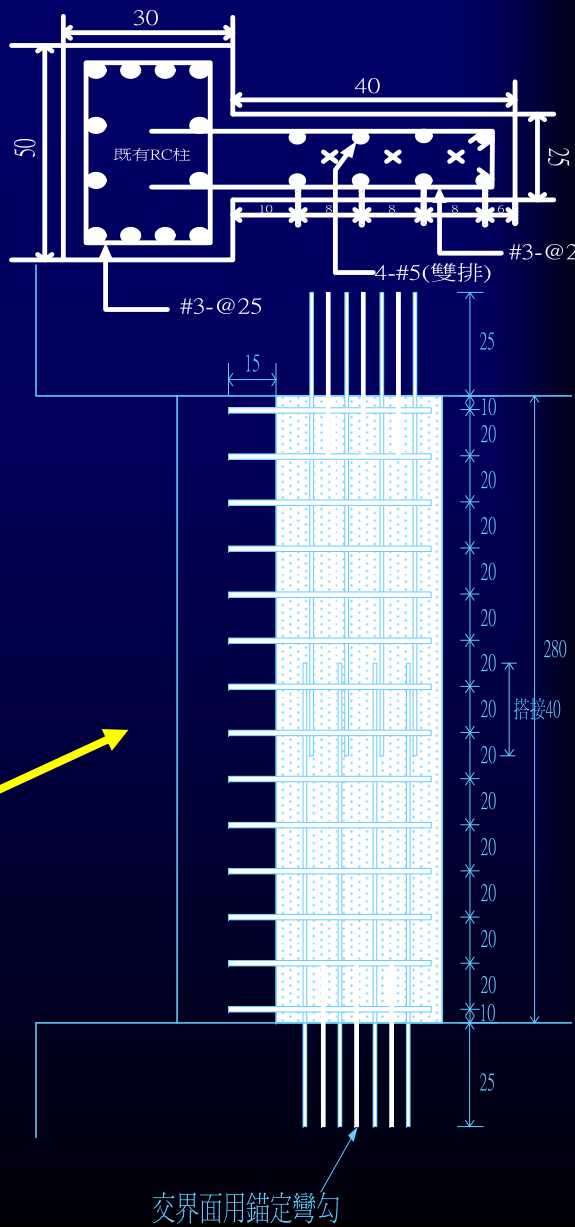


$V_{prototype}$= 48.2 t

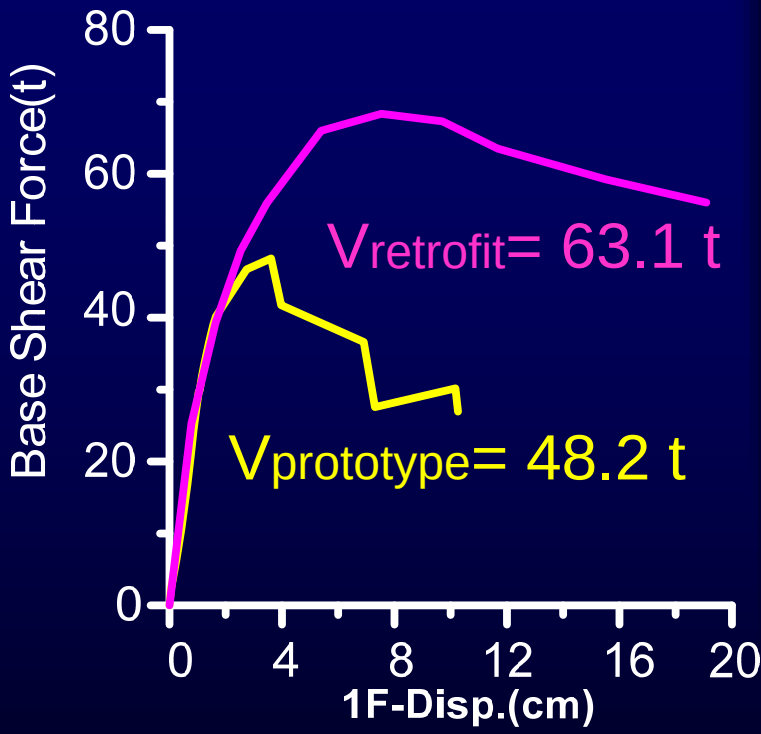
Failure mode: Shear failure of captive columns

Retrofit by adding Wing Walls





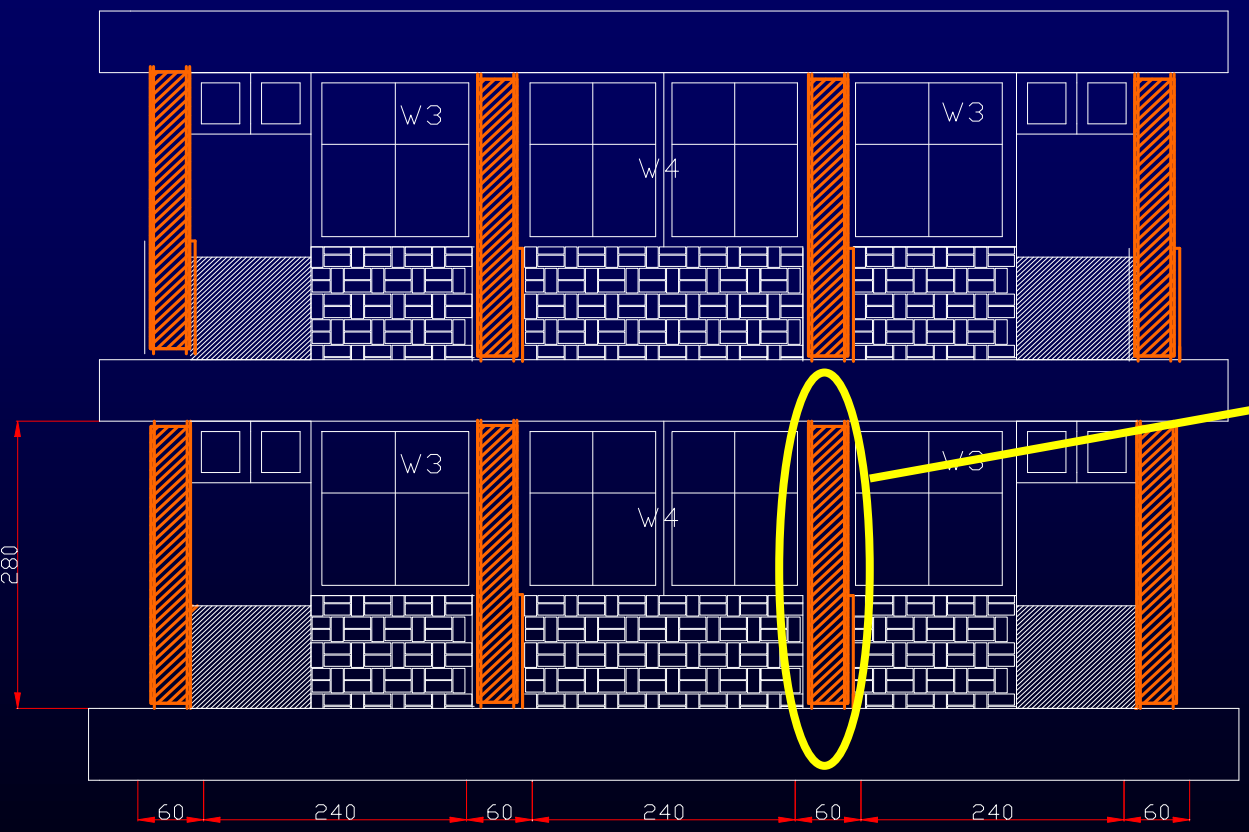
Test Result(2) – Wing Walls

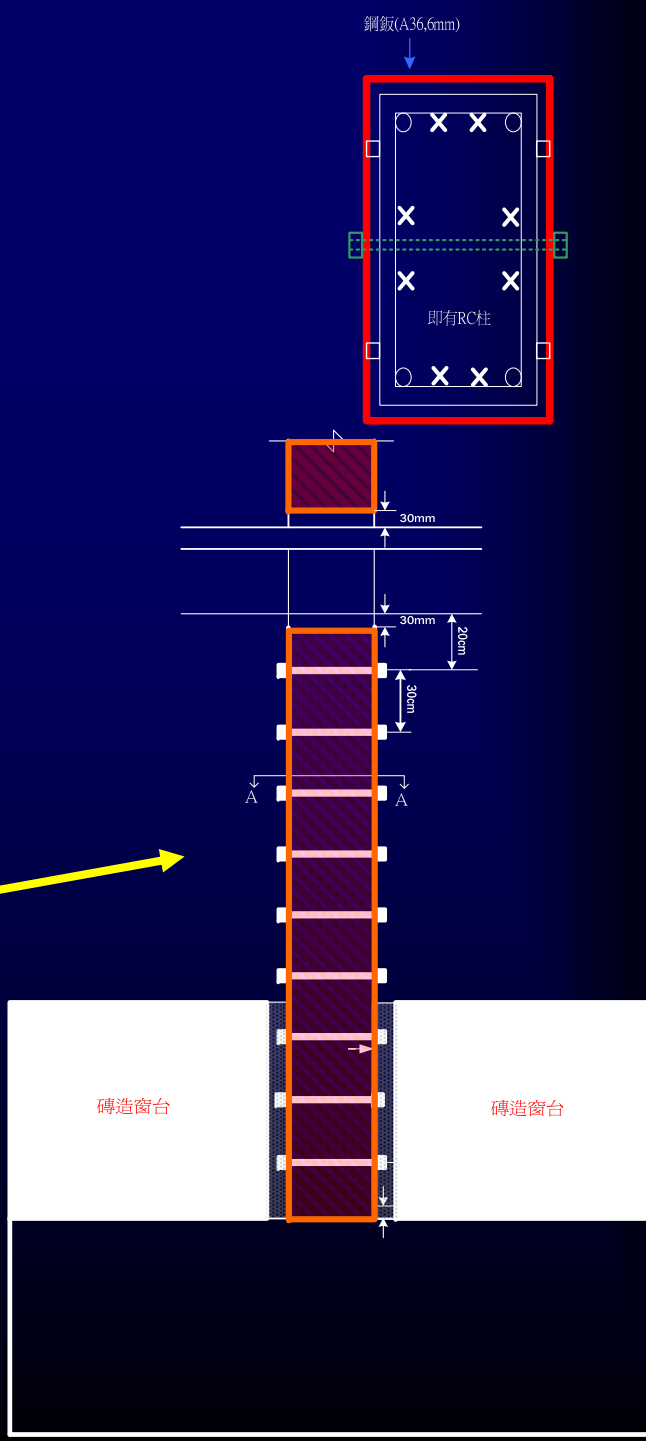


Failure Modes：Beam – Flexural Failure

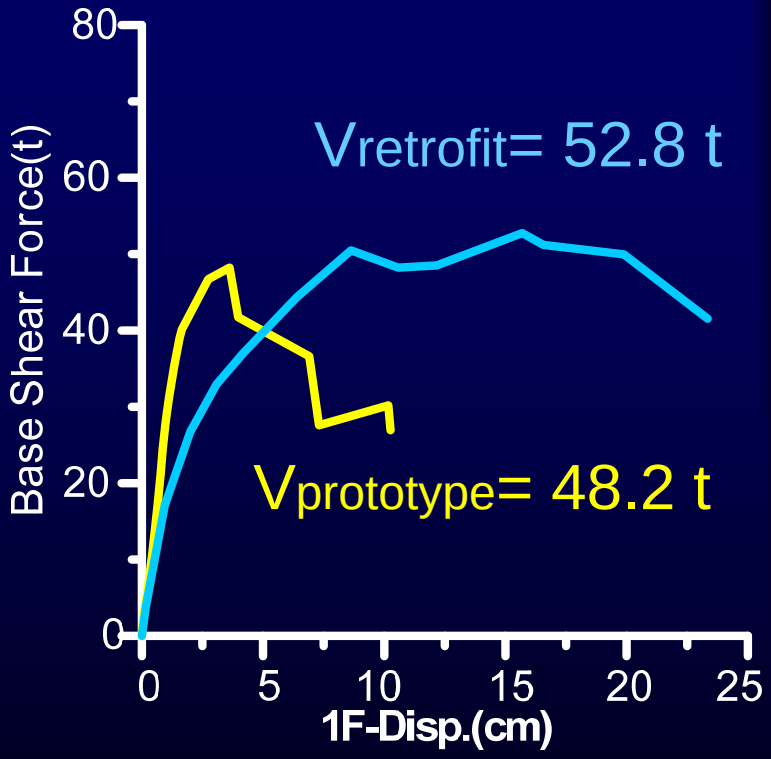
Joint – Shear Failure

Retrofit by using
Steel Jacketing





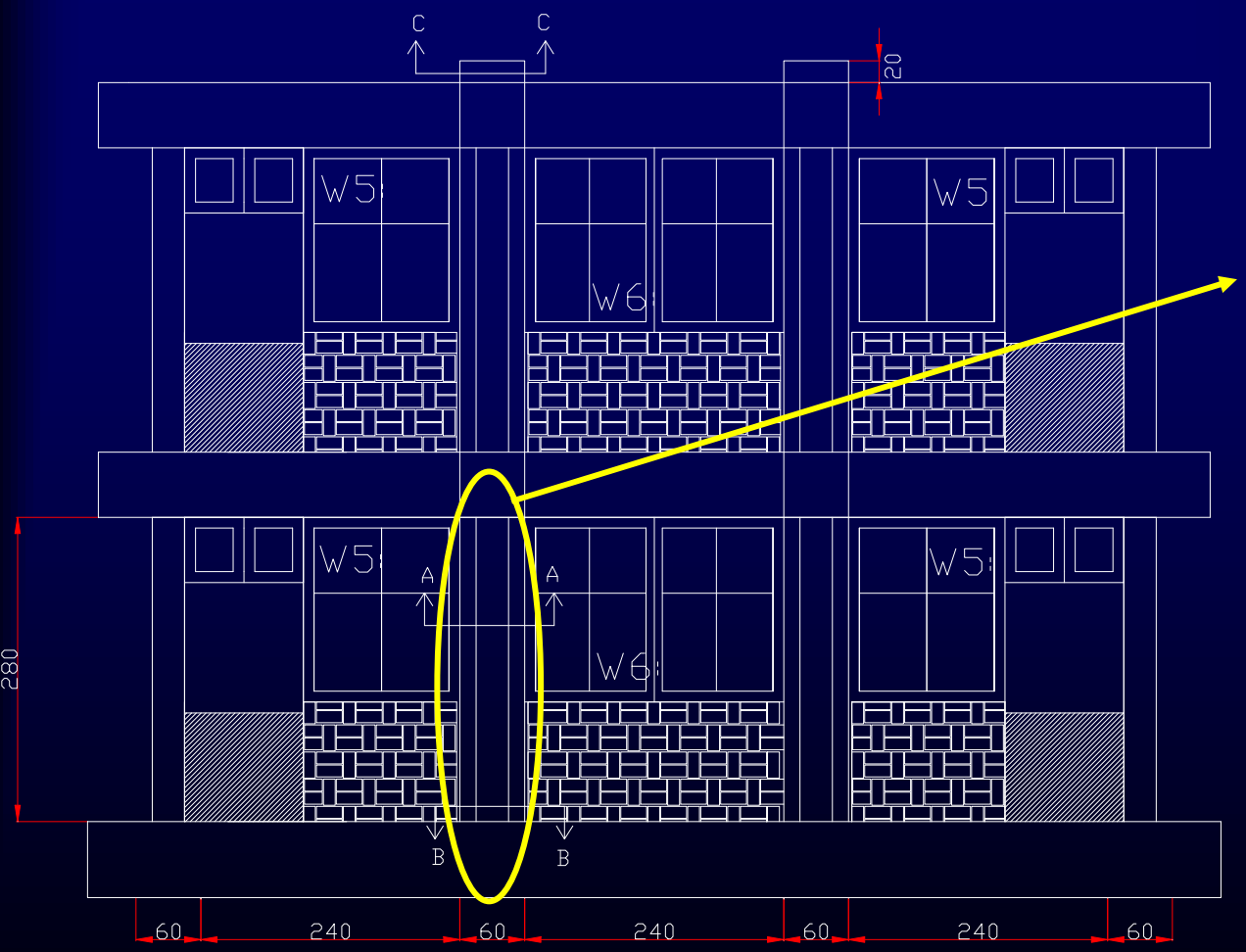
Test Result(3) – Steel Jacketing

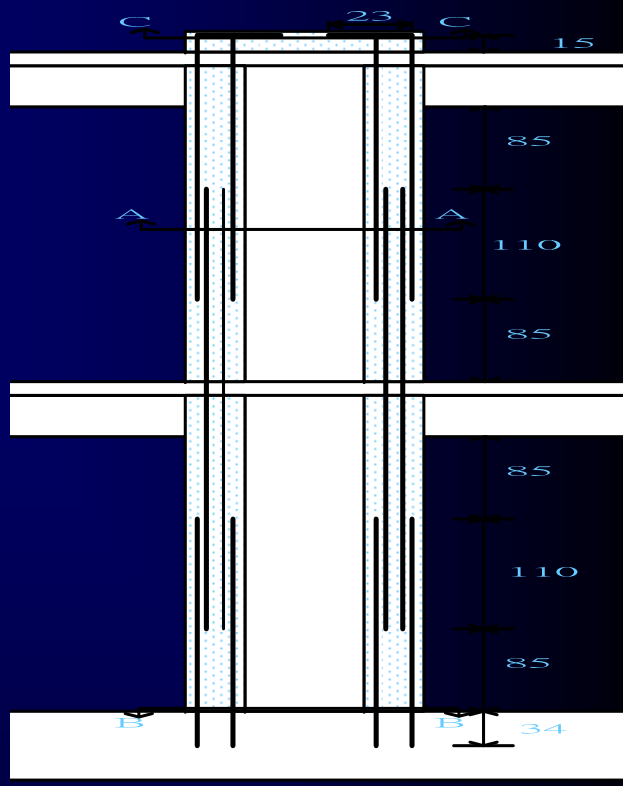


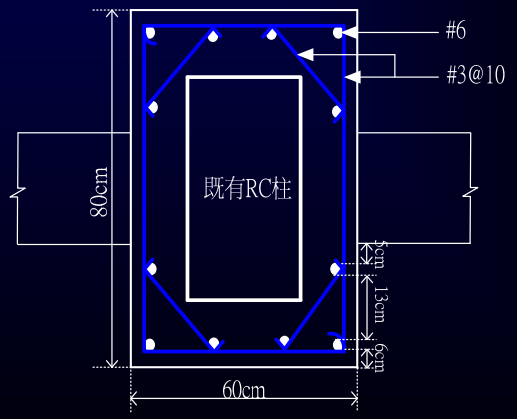
Failure Modes：Beam – Shear Failure

Joint – Shear Failure

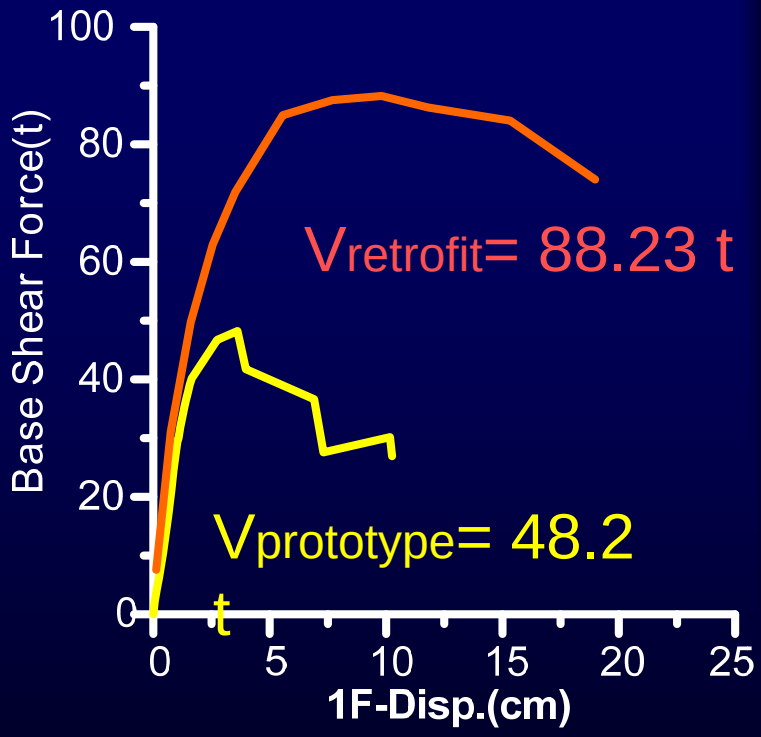
Retrofit by using
RC Jacketing







Test Result(4) – RC Jacketing



Failure Mode: Interior column – Flexural Failure