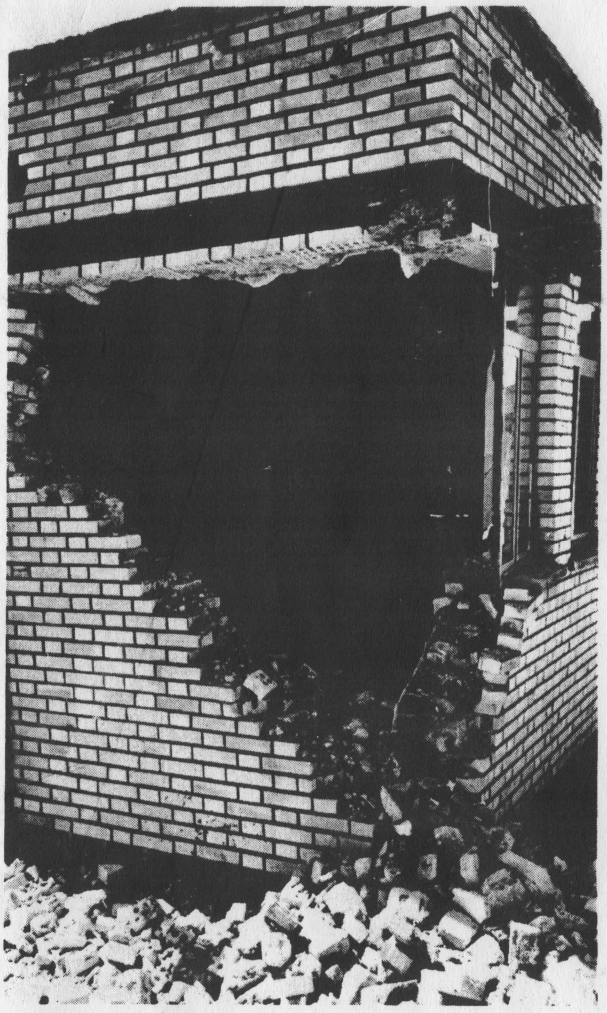
EDUCATIONAL BUILDING DIGEST 2

UNESCO REGIONAL OFFICE FOR EDUCATION IN ASIA, P.O.BOX 1425, BANGKOK

SMALL BUILDINGS IN EARTHQUAKE AREAS



TYPICAL FAILURE

- LOAD BEARING WALL: LOW QUALITY BRICK IN LIME MORTAR
- CLADDING: HIGH QUALITY BRICK IN CEMENT MORTAR
- CORNER NOT REINFORCED
- WINDOWS TOO CLOSE TO CORNER

INTRODUCTION

This publication is not written for the professionally qualified architect or engineer but for builders and others who actually construct small buildings in earthquake areas of not more than 120 sq.m. in area and not more than two storeys in height.

Larger buildings or small buildings of critical importance housing machinery for water or electrical supplies must be designed by a qualified engineer or architect.

Translation of this publication into the local language; its adaptation to local circumstances; its distribution to builders and others concerned with the construction of small buildings in earthquake areas, would greatly assist in the prevention of loss of life, injury to persons and damage to buildings.

Acknowledgements are made to the Director of the Building Research Establishment, United Kingdom, for his kind permission to produce this Digest which is based on a handbook on the design of small buildings in earthquake areas by A.F. Daldy.*

* Daldy, A.F. ***Small buildings in earthquake areas.*** Garston, Eng., Building Research Establishment, Department of the Environment, 1972, 41 p.

B. General

1. classification of seismic conditions

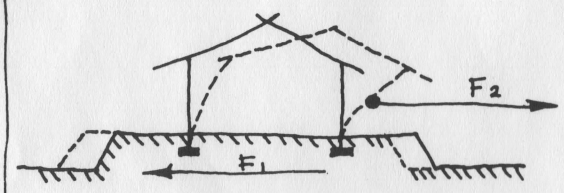
(i) ground - good (rock)
- average
- weak (clay)

(ii) intensity - minor
- moderate
- major

combination of (i) and (ii) indicates the seismic condition of an area:

- minor seismic conditions: (i) good, average (ii) minor
- moderate " " : (i) weak (ii) minor
  or (i) good, average (ii) moderate
- severe " " : (i) weak (ii) moderate
  or (i) good, average (ii) major

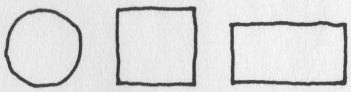
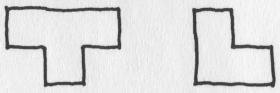
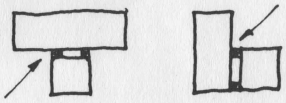
2. mechanism

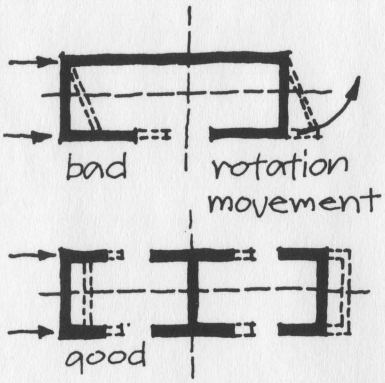
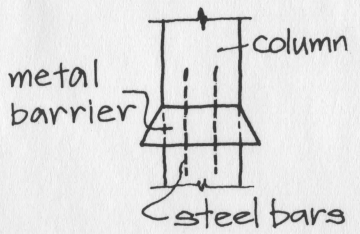


F_1 = action force caused by sudden acceleration of ground
a = acceleration due to earthquake
F_2 = reaction force caused by "not following" of mass m
m = mass of construction

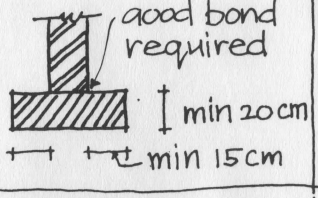
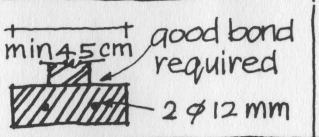
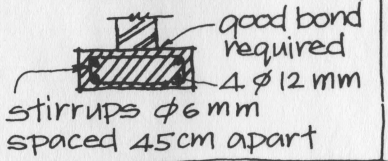
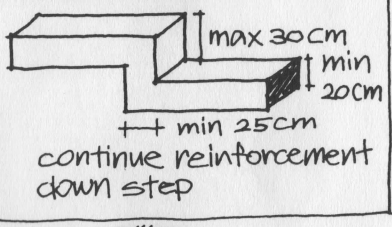
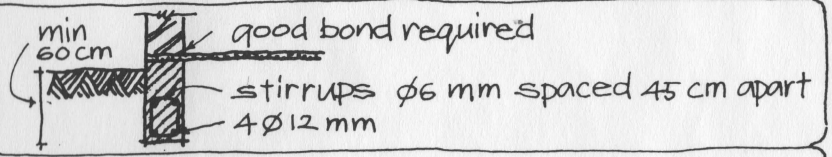
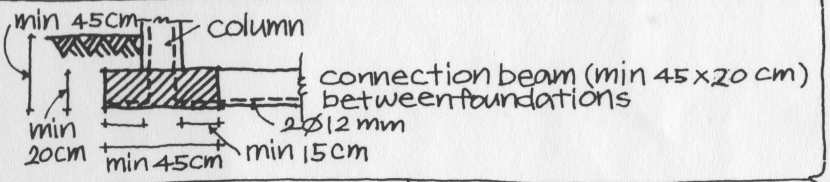
Law of Newton : $F = m \cdot a$
- general principle: reduction of m . gives a reduction of F
  (light weight construction recommended)

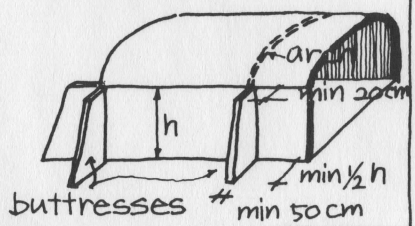
C. General Construction And Design Principles

1. round, square and short rectangular building plans are recommended	 good building plans	these building forms have an equal rigidity in all directions
2. avoid T or L shape without "crumple section"	 bad building plans	different vibration qualities of two parts will cause high stresses at joints
3. if T or L shape buildings are required, use "crumple section" fill "crumple section" with plaster and chicken wire	 good building plans with "crumple section"	"crumple sections" are easily repairable
4. provide as few wall openings as possible.	 large openings = building has no rigidity in directions A and B	see F_2

5. buildings to be symmetrical about center lines		as the rear wall is more rigid than the front wall, the building, when shaken, will tend to rotate in the direction indicated less tendency for a symmetrical building to rotate
6. use light weight roof construction where possible		see B2
7. tie all structural parts together		see D4 E1 E2 F7 G1 G4 H2 I1 I2 I3 I5 J etc.
8. reinforce the building	- over the top of the walls (ring beam) - vertically along openings - inlintels over openings - horizontally in walls - vertically at wall intersections and corners	see F3 see F5 see F7 see F6 see F5
9. materials	use materials of reasonably good quality all materials to be of equal quality	the weakest part of the building may cause total collapse
10. supervision and inspection	ensure (i) that the materials meet specifications and (ii) are properly stored on the site (iii) that workmanship is good	
11. prevention against rot, fungi-, insect- and termite attack	by: - pressure impregnation of wood - use of mechanical barriers - soil poisoning 	barrier provides slip surface on which upper part of building can slide during earthquake: reinforce with steel bars
12. maintain the building properly		

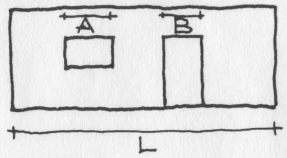
D. Foundations

1. foundations down to firm ground		see B1
2. strip foundations		
a. minor seismic condition: concrete mix 1:3:5 (1 cement, 3 sand, 5 coarse aggregate)		a good bond between wall and foundation is required: no slip at surface during earthquake
b. moderate seismic condition: concrete mix 1:2:4		increase strength of foundation
c. severe seismic condition:		increase strength of foundation further
d. use of stepped footings: only in minor and moderate seismic conditions		ensure continuity of strip foundation
3. narrow strip foundation		
4. column foundation concrete mix 1:2:4		
5. pile foundation	connect pile tops, below ground level with reinforced concrete beam	increase rigidity of construction

E. Earth Walls	are structurally weak; if use cannot be avoided, they need special care in construction	
1. buttresses -two at each corner. -at cross walls, arches etc.	-well bonded into wall -constructed at same time as wall 	-good connection is essential -avoid shrinkage cracks buttresses prevent the spreading of walls and increase the strength of the building

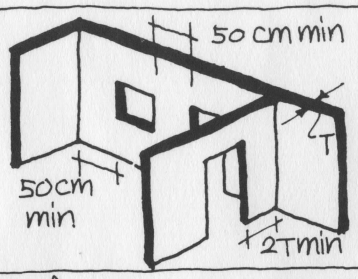
2. openings in walls

a. not larger than necessary, in any case:
(A+B) < 1/3 L



openings lead to reduction in strength of walls and of the connection between walls

b. openings should not be close to:
- other openings
- to corners
- to wall intersections



3. provide ringbeam at top of wall, over all walls

ring beams prevent spreading of walls and stiffen the building

a. anchor beam to all walls

dowels each 120 cm, min ϕ 12 mm
projected min. 10 cm into beam and min. 23 cm into wall

b. use concrete mix 1:2:4

c. dimension ring beam properly.
- provide continuous reinforcement all around.

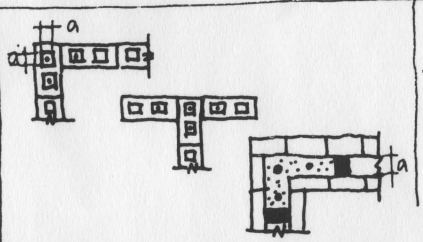
main walls (> 10 cm wide)
width of ring beam = width of wall
- in minor seismic condition:
depth of ring beam 15 cm, reinforcement 4 ϕ 12 mm, stirrups ϕ 6 mm spaced 37 cm apart
- in moderate seismic condition:
depth of ring beam 20 cm, reinforcement 4 ϕ 16 mm, stirrups ϕ 6 mm spaced 25 cm apart
- in severe seismic condition:
depth of ring beam 20 cm, reinforcement 4 ϕ 20 mm, stirrups ϕ 6 mm spaced 25 cm apart

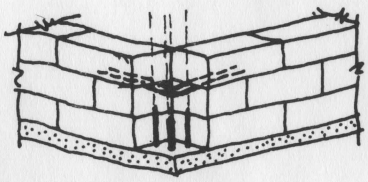
partition walls (< 10 cm wide)
width of ring beam = width of wall
2 ϕ 12 well anchored into main ring beam

4. wall construction must be of good quality

for mortar: see F1

5. provide vertical wall reinforcement
- at corners
- at intersection
- along openings
- anchor all reinforcement into ring beam and foundation





- shortest dimension of the cavity (a) should not be less than 5 cm
- fill the cavity with fine concrete mix 1:2:2
- use ϕ 12 mm steel bars

6. horizontal reinforcement

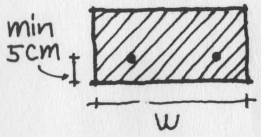
a. anchor well to vertical reinforcement

b. stone masonry walls should not be used in severe seismic condition	<u>load bearing walls</u> reinforcement: 3ø12 mm bars or strip of expanded metal for full width of a wall minus 2.5 cm cover at each side <u>non load bearing walls</u> reinforcement: 1ø12 mm bars spaced 45 cm apart
c. block / brick walls	reinforcement: 2ø6 mm bars spaced 45 cm apart or strip of expanded metal for full width of wall minus 2.5 cm cover at each side

7. lintels are required over all openings

a. all lintels should be reinforced, and have adequate bearing at ends

width of lintel = width of wall
one reinforcement bar
for each 13 cm width



eg 2 bars: width (w) can vary from 13 to 26 cm

span opening	lintel depth	bar size	bearing
< 45 cm	15 cm	-	15 cm
45 - 125 cm	15 cm	ø12 mm	23 cm
125 - 180 cm	23 cm	ø20 mm	30 cm
> 180 cm	consult qualified engineer		

b. connect lintel reinforcement to all vertical reinforcement

c. -where lintels form continuous beams (ring beam, see F3), dowels must be used to anchor the lintel to the walls.
-use ø12 mm spaced 1.20 m apart projecting not less than 23 cm into the wall, and not less than 10 cm into the beam.

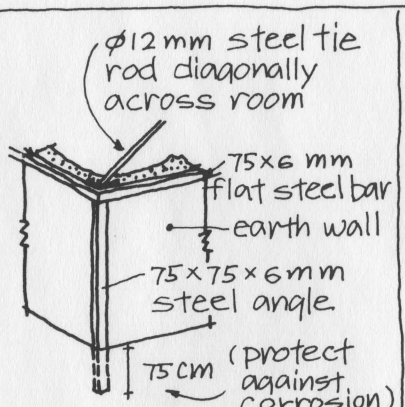
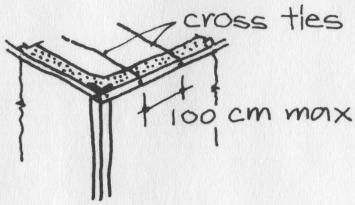
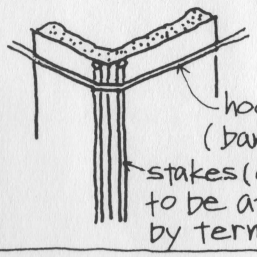
8. damp proof course

a. use material that will bond well to the wall to prevent slip in an earthquake

b. when doubt exists about bond of the damp proof course, use ø12 mm dowels 40 cm long spaced 50 cm apart

c. damp proof course 20 mm thick consisting of cement and sand 1:3 is satisfactory

2. reinforce walls

a. square building plans: at corners and wall intersections use steel angles		this reinforcement prevents the spreading of walls and increases the strength of the building
b. in long building plans, where not possible to use diagonal ties, use cross ties spaced 1m apart		this reinforcement prevents the spreading of walls and increases the strength of the building
c. where no steel is available: stakes and hoop-iron are a better solution than nothing		this reinforcement prevents the spreading of walls and increases the strength of the building

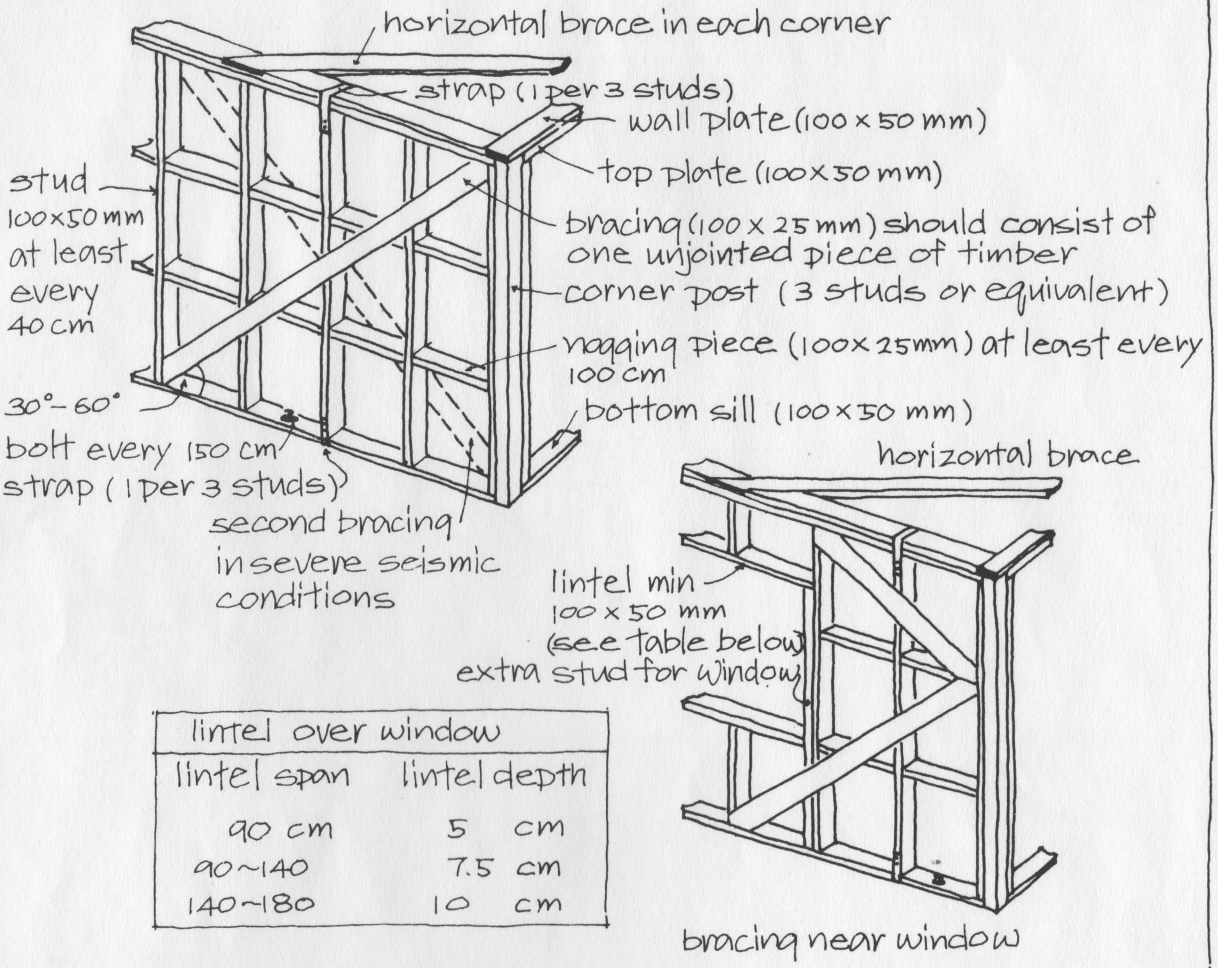
F. Brick, Block, Stone Walls

1. mortars

a. do not use mud-mortar or lime mortar		shrinkage of mud or lime-mortar after drying out leads to loss of bond
b. composite mortars of cement/lime/sand mix 1:1:8 are better	-use mortar within 25 min after adding water -wet surfaces before applying mortar	
c. cement and sand mortar mix 1:5 or 1:6 is good	-use mortar within 25 min after adding water -wet surfaces before applying mortar	
d. do not use cement and sand mortar 1:3		1:3 mortar shrinks and cracks too much when it dries

G. Timber Frame Buildings / Timber Construction

1. framing



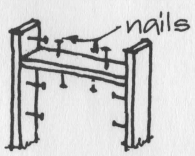
bracing near window

lintel over window	
lintel span	lintel depth
90 cm	5 cm
90~140	7.5 cm
140~180	10 cm

2. wall-covering

a. timber wall covering securely fixed to stiffen building

b. sheets of asbestos cement or other material should have edges fixed to timber

c. 

heavy infill panels of bricks or stone in mortar should be secured to prevent falling out

3. timber columns

a. must always be well connected at top and bottom

b. - not to extend below termite barrier
- not to extend into concrete
- not to extend into ground

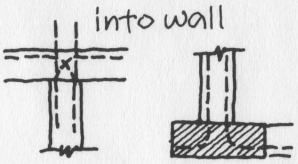
precautions to prevent deterioration of timber

4. timber beams must be well connected to each column

H. Reinforced Concrete (R.C.) Construction

1. R.C. construction should normally be designed by a qualified engineer

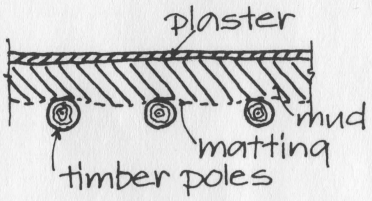
2. important connection



- connection of beam to column or column to wall
- connection of column to foundation
- column foundation should be connected to nearest columns in both directions by a R.C. beam (see D4)

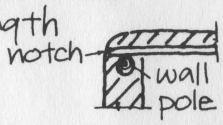
I Heavy Roofs	are not recommended	see B2

1. mud roof



this type of roof is very heavy and when it collapses it may cause loss of life

improve stability and increase strength



- strengthen walls
- introduce wall plate and connect wood pole to the wall plate (wall pole)
- slope roof not less than 1:40 to drain quickly

2. thatch roof
- space buildings far apart to reduce fire risk
- roof slope not less than 45°
- provide ring beam and tie rods at ceiling/eaves level
- metal sheeting (old, flattened petrol cans, etc.) fixed to under side of thatched roof over cooking area or fire place will assist in prevention of spread of fire

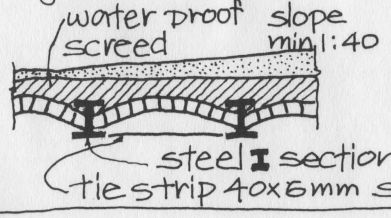
- heavy when wet
- fire risk when dry

3. tiled roof
- tie rods and ringbeam at ceiling level
- wall plate fixed to ring beam
- rafters and trusses fixed to wall plate

prevent roof and walls from spreading

4. reinforced concrete roof
- should be designed by qualified engineer
- ensure good supervision and workmanship

5. jack arches



- I section to bear on concrete pad 30 cm long or on ring beam, and fixed to ring beam
- when I sections are 1 m apart, span of 150x75 I beam should not exceed 4 m

J Light Weight Roof

always to be recommended
- fix ceiling well
- fix wallplate to ring beam (ø 12 mm spaced 150 cm apart)
- fix trusses securely to wall plate
- bracing in roof in longitudional direction

K. Chimneys, Flue pipes

- often break at roof levels - flue pipes are better than masonry chimneys - reinforce masonry chimney with 4 ø 12 mm bars well bonded into walls - use cement and sand mortar	collapse causes great damage and fire risk see F5

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