A STUDY OF BUILDING CODE REQUIREMENTS FOR SMALL REINFORCED CONCRETE BUILDINGS SUBJECTED TO EARTHQUAKE FORCES

by

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SYNOPSIS

The main purpose of this report was to illustrate the procedure for constructing an economical and safe small reinforced concrete building capable of withstanding earthquake forces. In a properly designed concrete structure this aim can be achieved at very little, if any, added expense. This is particularly true in small buildings.

It is necessary for us to be familiar with the building code requirements and design loads before investigating the structural safety for the earthquake shocks. There are slight differences among the requirements of the various codes, but in accordance with local situations they can be properly applied.

Some experimental results are presented to demonstrate how to prevent the cracks that occur in floors at the corners, and around openings in floor slabs.

Separate discussions on parapet walls, bearing walls, floors, footings, cross walls, and an analysis of a two-story house are presented in this report.

INTRODUCTION

Most of the major earthquakes of record have occurred in a narrow region surrounding the Pacific Ocean, the Circum-Pacific Belt, and is a region extending across Asia to southern Europe and northern Africa, called the Alpide Belt. However, earthquakes are by no means restricted to these areas. In the United States we think of the west coast as being the earthquake region.

Correctly designed schools, apartments, office buildings and other large structures have performed well in recent earthquakes. The attention of architects and engineers has long been directed toward the solution of the problem of making such buildings earthquake resistant, and the results are gratifying.

In general, the same principles of design and construction involved in making large buildings resistant to earthquakes are applicable to the small store, garage or house. A rigorous analysis is not always necessary and certain assumptions can safely be made to simplify the design procedure. In this report rational recommendations for design and suggestions pertaining to construction are presented that will insure safe, economical small buildings. Typical examples are worked out in detail to illustrate design principles.

BUILDING CODE REQUIREMENTS AND DESIGN LOADS

Forces due to wind and, in some instances, horizontal earthquake forces to be considered in the design are established in building codes to insure the safety of buildings. There is little difference between the requirements of the various codes. A building can be properly designed in accordance with any one of them and will safely resist earthquakes.

In compiling the data given below, the following codes have been consulted:

Uniform Building Code by Pacific Coast Building Officials Conference, 1952.

1. Los Angeles City Building Code, 1953
2. Riley Bill as Amended (California Statutes, 1953, Chapter 1766)
3. Building Code Requirements for Reinforced Concrete of the American Concrete Institute (ACI 318-51)
4. Title 21 of California Administrative Code, 1953

Since earthquake stresses in a structure occur infrequently, it is considered conservative to increase the normal working stresses for combining dead load, live load and earthquake force as it is done for combining dead load, live load and wind load in regular designs that consider the effect of wind.

For all structural elements, the Los Angeles Pacific Coast and Title 21 permit a 33 1/3 percent increase. Normal working stresses are given in Table 1, in which f'_c is the ultimate compressive cylinder strength of the concrete at 28 days.

Table 1. Allowable working stresses for reinforced concrete.

Description	For any strength of concrete	For particular strength of concrete f'_c 2,000 psi	f'_c 2,500 psi	f'_c 3,000 psi
Flexure: f_c				
Extreme fiber in compression	$0.45 f'_c$	900	1,125	1,350
Extreme fiber in tension	$0.03 f'_c$	60	75	90
Shear: v				
Beam with no web reinforcement	$0.03 f'_c$	60	75	90
Beam with properly designed web reinforcement	$0.12 f'_c$	240	300	360
Footings	$0.03 f'_c$	60	75	75
Axial compression:				
Spirally reinforced columns	$0.225 f'_c$	450	560	675
Tied reinforced columns	$0.18 f'_c$	360	450	540
Bond: u				
Top bars	$0.07 f'_c$	140	175	210
All others	$0.10 f'_c$	200	250	300
Bearing:	$0.25 f'_c$	500	625	750

The live load not only enters into the design of the structural elements as a vertical load, but also combined with the dead load, as in the case of tanks and warehouses. It is also used as a measure of the horizontal earthquake force. In Table 2 are listed minimum allowable live loads for various occupancies.

Table 2. Minimum allowable live loads.

Description	Los Angeles	Title 21	Pacific Coast
Apartments, dwellings	40		40
Auditoriums	Sloped-50 Level-100	Sloped-50 Level-100	Fixed seats-50 Movable-100
Stairways	100	75	100
Libraries	50	50	60
Libraries, stack rooms		100	125
Manufacturing			125
Offices	50	50	50
Roofs	20	20	20
Schools	40	50	100
Storage-light	200-300		125
Storage-heavy			250
Stores			100

In order to express earthquake design loads, we use the formula

$$F = C\ (\ W_d + k\,W_l\ )$$

where F = lateral force of earthquake

W_d = total weight including machinery and other fixed loads

W_l = total live load

k = coefficient dependent on nature of live load (Table 3)

C = coefficient dependent on structural element of the building under consideration (Tables 4 and 5)

Table 3. Values of k[1].

Type of structure	Los Angeles	Title 21	Pacific Coast
Warehouses	0.5	0.5	0.5
Tanks	1.0	1.0	1.0
Other than warehouses, tanks	0.0	0.0	0.0

Table 4. Values of C for entire structures[1].

Type of structure	Los Angeles	Title 21	Pacific Coast
All buildings	$\frac{0.60}{N + 4.5}$	$\frac{0.60}{N + 4.5}$	$\frac{0.15}{N + 4.5}$

N is the number of stories above the story under consideration

1. "Analysis of Small Reinforced Concrete Buildings for Earthquake Forces," Portland Cement Association, 1955, p. 12.

Table 5. Values of C for parts of structures[2].

Parts of structures	Los Angeles	Title 21	Pacific Coast
Parapet and cantilever walls	1.00	1.00	0.25
Other walls	0.20	0.20	0.05
Roof structures, tanks and contents, towers and chimneys	0.20	0.20	0.05

2. "Analysis of Small Reinforced Concrete Buildings for Earthquake Forces," Portland Cement Association, 1955, p. 12.

EARTHQUAKE STRESSES IN BUILDINGS

Earthquakes consist of horizontal and vertical ground vibrations. The horizontal motion is usually much greater than the vertical, the latter being from one-tenth to one-fifth of the former. The vertical vibrations are generally so small that they may be disregarded. The "safety factor" with which a building is designed will take care of the increases in stress due to vertical earth movements.

The most destructive force is caused by horizontal earth motion. When the ground underneath a structure is moved suddenly to one side, the building will tend to remain in its original position because of its inertia. The acceleration (rate of change in velocity) of the horizontal movement varies and its maximum value is the yardstick commonly adopted for measuring the equivalent static force. If the maximum acceleration of the horizontal earth movement is one-tenth the acceleration due to gravity, it is assumed that the stresses in the structure caused by the earthquake are the same as those produced by horizontal static forces equal to one-tenth of the gravity forces acting on the building.

When the horizontal forces have been decided on, the stresses can be computed in a manner similar to the determination of wind stresses. A certain percentage of the mass at each floor is assumed to act at that level in a horizontal direction. In addition, since all parts of a building, exterior as well as interior, are subjected to the lateral earthquake force, they must be considered in the stress analysis.

Buildings should be designed to resist lateral forces in any direction because an earthquake may occur in any direction. The earth movement, however, can be replaced by two components acting parallel to the axes of the building; therefore, it is sufficient to investigate its strength in two perpendicular directions.

The lateral forces must be resisted by the walls or by the framing system. Partitions and outside walls parallel to the direction of the earth movement (cross walls) possess much greater strength and rigidity against distortion than those normal to this direction.

Figure 1 shows diagrammatically the distribution and magnitude of stresses caused in a cross wall by the downward transmission of accumulated lateral forces. If the wall thickness is uniform, both shearing and bending stresses will increase in the lower stories.

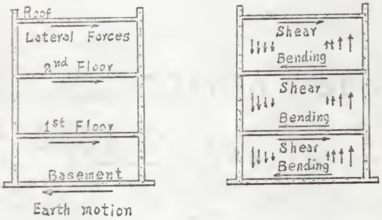

Fig. 1. Forces and stresses due to earth action.

Adjacent buildings or parts of the same building dissimilar in mass or stiffness should be sufficiently separated to prevent them from pounding one another during an earthquake because of different rates of movement. Figure 2 shows an arrangement of these special joints for a group of buildings or for a building with large wings. The separation should be carried down to the top of the foundation, which may be continuous for an entire group of buildings.

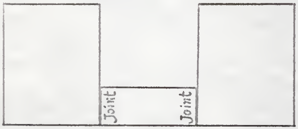

Fig. 2. Separation of adjoining buildings.

PARAPET WALLS

A parapet wall presents a special hazard during an earthquake because, being entirely above the roof line, it is usually free-standing and therefore less securely held in place than walls supported at top, bottom and sides. To minimize this hazard, parapets should be tied firmly to the roof and to the wall below. This is best accomplished with reinforced concrete construction in which adequate reinforcement is anchored into the roof slab and wall below. At the roof line, slab reinforcement should be carried well into the wall and a 6-in. fillet, reinforced as shown in Fig. 4 should be provided to insure adequate anchorage and stiffness.

During an earthquake, a parapet wall acts as a vertical cantilever subjected to a horizontal force. Certain building codes (Los Angeles, Title 21 and Pacific Coast, Zone 3) require that a parapet wall shall be designed for a lateral force equal to its own weight, or $F = wh$, in which F is the total lateral force per lineal foot of wall, w is the weight of wall per square foot and h is the height of the wall above the roof slab.

Where the parapet wall joins the roof slab, this force produces a bending moment, $M = 1/2\ Fh = 1/2\ wh^2$, which may cause tension in either face depending upon the direction of the earthquake.

Example: Parapet wall subject to lateral force

To illustrate the analysis of a parapet wall, Fig. 3 shows an 8-in. wall 4'6" high, using 3,000 lb. concrete[2].

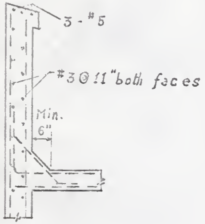

Fig. 3. An 8-in. parapet wall.

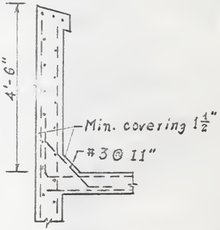

Fig. 4. An 8-in. parapet wall.

Design for a lateral force equal to its own weight.

$$F = wh = 2/3 \times 1 \times 4.5 \times 150 = 450 \text{ lb./ft.}$$

$$M = 1/2\ wh^2 = 1/2\ Fh = 1/2 \times 450 \times 4.5 = 1013 \text{ ft.lb./ft.}$$

May increase f_s and f_c by 1.33 for earthquake condition.

$$f_s = 20{,}000 \text{ psi} \times 1.33 = 26{,}700 \text{ psi.}$$

$$f_c = 1350 \text{ psi} \times 1.33 = 1800 \text{ psi.}$$

$$A_s = \frac{M}{f_s \times 7/8 \times d} = \frac{1013 \times 12}{26{,}700 \times 7/8 \times 6.25} = 0.084 \text{ in.}^2\text{/ft.}$$

Use #3 bars 15" c-c. $A_s = 0.089$ in.^{2}/ft.

Check temperature steel

Vertical steel

$8 \times 12 \times 0.002 = 0.192$ in.^{2}/ft.

Compare temperature steel to steel required for earthquake

Temperature steel $= 0.192$ in.^{2}/ft.

Earthquake steel $2 \times 0.089 = 0.178$ in.^{2}/ft.

$0.192 > 0.178$ so temperature controls.

Use #2 bars 13" c-c both faces $A_s = 2 \times 0.1 = 0.2$ in.^{2}/ft.

Longitudinal steel

$8 \times 54 \times 0.002 = 0.86$ in.^{2}/ft.

Use 8 #3 bars $A_s = 0.88$ in.^{2}/ft.

BEARING WALLS

A bearing wall should be designed for a lateral force normal to its surface. According to the Title 21, Los Angeles, and Pacific Coast, Zone 3 codes, a wall must be designed to resist a minimum horizontal force of 0.2 of its weight.

Although a wall is generally supported laterally on four sides, it is ordinarily designed to carry horizontal loads over the shortest span, and in buildings this will usually be the vertical direction. It is also important to provide adequate reinforcement at right angles to the main reinforcement in order to resist volume-change stresses and to insure unity of action. Figure 5 shows minimum reinforcement for walls that are 8 in. thick.

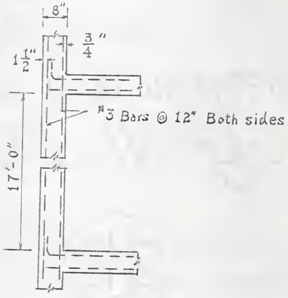

Fig. 5. Reinforced concrete wall.

Example: Wall Subject to Lateral Force

Design an 8" thick, 17' high, solid wall (no windows)

Assume wall is simply supported, both top and bottom (no fixed ends)

Lateral force = 0.2 × wt. of wall

F_s = 26,700 psi.

$w = 0.20 \times 1 \times 1 \times 2/3 \times 150 = 20$ lb./ft.

$$M = \frac{wL^2}{8} = \frac{20 \times 17 \times 12}{8} = 8{,}660 \text{ in.lb.}$$

For bending disregarding steel in compression

$$A_s = \frac{M}{f_s \times j \times d} = \frac{8660}{26{,}700 \times 7/8 \times (8 - 1.5 - 0.25)} = 0.06 \text{ in.}^2\text{/ft.}$$

$$A_s = 0.002 \times 12" \times 8" = 0.18 \times 1/2 = 0.09 \text{ in.}^2$$

Temperature steel controls

Use 3# bars 12" c-c.   Both sides and both directions = 0.11 in.^{2}

FLOORS

In order that lateral earthquake forces may be transmitted to the foundation of a building, these forces should be distributed to vertical members capable of transferring them downward. This is accomplished by reinforced concrete walls which act as very deep and stiff vertical girders or by rigid frames consisting of columns and beams. The floors serve as horizontal girders of great rigidity when constructed of concrete, and distribute to walls and frames the latter forces due to dead load and superimposed load multiplied by the proper seismic factor.

Concrete floors having relatively small openings and designed for static loads possess adequate strength to function as distributing diaphragms, as will be demonstrated in the following example.

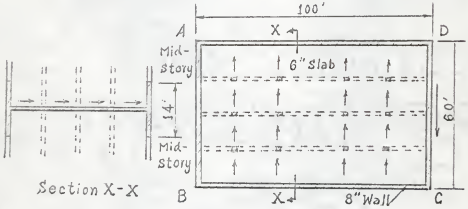

Fig. 6. Diaphragm action of floor slab.

Example: Solid Slab Floor Acting as Horizontal Girder

In order to illustrate the action of the floor as a horizontal girder, consider a part of a rectangular warehouse building as shown in Fig. 6, with intermediate columns carrying the floors. These columns will not be considered as resisting any lateral forces. The floor must transmit to the end walls, AB and CD, horizontal forces due to the live load plus the dead load of the floor, walls and columns (shown in Section X-X) multiplied by the seismic factor. The walls are considered to be without windows. If there is considerable window area, some reduction in weight of walls is permissible.

If the seismic factor is 0.10, the lateral forces will be as follows:

From Floor slab:	$100 \times 60 \times 75 \times 0.10 =$	45,000 lb.
From walls AD, BC:	$200 \times 14 \times 100 \times 0.10 =$	28,000 lb.
From beams:	$15 \times 20 \times 225 \times 0.10 =$	6,750 lb.
From columns:	$12 \times 12 \times 150 \times 0.10 =$	2,160 lb.
From live load:	$100 \times 60 \times 125 \times 0.10 =$	75,000 lb.
Total		156,910 lb.

The average shearing stress at the end walls due to this horizontal load is one-half the total force divided by the cross-sectional area of the floor slab, or

$$\frac{F}{2A} = \frac{1}{2} \times \frac{156,910}{60 \times 12 \times 6} = 18 \text{ psi.}$$

and the maximum bending moment may be taken as

$$M = \frac{1}{8} \times 156,910 \times 100 \times 12 = 23,540,000 \text{ in.lb.}$$

The maximum flexural stress is approximately the bending moment divided by the section modulus of the slab neglecting the beam webs,

$$f = \frac{M}{S} = \frac{23,540,000}{1/6 \times 6 \times 720^2} = 45 \text{ psi.}$$

Since the modulus of repture of plain concrete of ordinary quality will exceed 200 psi, the flexural stress is easily resisted by the concrete without taking the steel in the slab into account.

Inspections of buildings show that cracks occur in floors at the corners A, B, C, and D, indicating a concentration of stress. It is therefore important that the corners be thoroughly reinforced. Figure 7 shows how this can be accomplished.

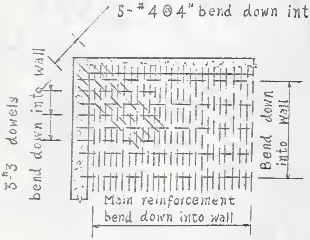

Fig. 7. Typical floor reinforcement at a corner.

Small openings up to 1 ft. in diameter, unless they occur at the columns, require no special provisions other than that the reinforcement should be bent around them.

Larger openings in floors weaken the slab and cause a concentration of stress. At such places an amount of reinforcement at least equivalent to that interrupted by the opening should be located as near the sides of the hole as possible without crowding. It is also desirable to place diagonal bars at the corners, as shown in Fig. 8.

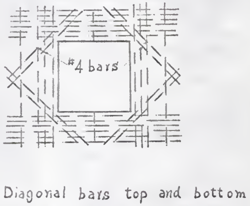

Fig. 8. Reinforcement around opening in floor slab.

CROSS WALLS

Cross walls are the walls in the direction of the earthquake forces. They are a very important means of transmitting forces to the foundation. They may be either exterior walls or partitions.

The first story of the end wall of a two-story building is shown in Fig. 9. A horizontal force of 30,000 lb. is assumed to be concentrated at the second floor level.

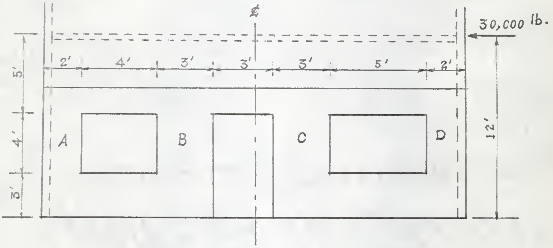

Fig. 9. 8 in. Cross wall.

The wall is assumed to consist of four separate piers and the horizontal load must be divided among them. In order to deflect pier B 0.1 in., a greater force is required than to deflect the small pier A. The total lateral load will be distributed among the individual piers in proportion to their rigidity, $1/\Delta$, where Δ is the deflection of the pier due to a unit force. This deflection is the sum of D_m and D_s

$$\Delta = D_m + D_s = \frac{PH^3}{12\ E_m I} + \frac{1.2\ PH}{AE_s}$$

where D_m = deflection due to bending

D_s = deflection due to shear

P = lateral force on pier

H = height of pier

I = moment of inertia of pier in direction of bending

A = cross-section area of pier

E_m = modulus of elasticity in compression

E_s = modulus of elasticity in shear.

$E_m = 3 \times 10^6$ psi, $E_s = 1.2 \times 10^6$ psi. Substituting the values for E_m and E_s in the above equation and using a unit force of $P = 10^6$ gives

$$\Delta = \frac{H^3}{36I} + \frac{H}{A}.$$

The calculations necessary for determining the distribution of lateral force are given below

Pier	width d in.	Ht. H in.	Area A in.^{2}	I in.^{4}	D_m $\frac{H^3}{36I}$	D_s $\frac{H}{A}$	Δ	$\frac{1}{\Delta}$	Proportion of shear	Force on each lb.
A	24	48	192	9,216	0.333	0.250	0.583	1.72	0.156	4,680
B	36	48	288	31,104	0.099	0.166	0.265	3.78	0.344	10,320
C	36	48	288	31,104	0.099	0.166	0.265	3.78	0.344	10,320
D	24	48	192	9,216	0.333	0.250	0.583	1.72	0.156	4,680

The height of piers is assumed to be the height of the openings between which they are located. If the openings are of different heights, as the door and window at the sides of pier B, the small height is used.

The shearing stresses equal $\frac{P}{A}$, for piers A and D,

$$\frac{4,680}{192} = 24.4 \text{ psi and for piers B, C, } \frac{10,320}{288} = 35.8 \text{ psi.}$$

Tensile and compressive stresses in the pier originate from three sources: 1. flexure, 2. overturning, 3. gravity loads. The point of contraflexure is at mid-height in Fig. 10.

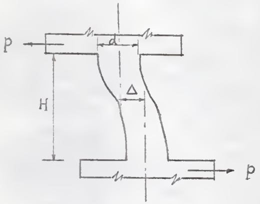

Fig. 10. Cross wall pier with top displaced.

The flexural moment at the bottom of the pier is

$$M = p \times \frac{H}{2}$$

and the maximum stress is

$$f = \frac{M \times 1/2\ d}{I} = \frac{PHd}{4I}.$$

The maximum flexure stresses for piers A and D are

$$f = \frac{4,680 \times 48 \times 24}{4 \times 9,216} = 146 \text{ psi.}$$

and for B and C are

$$f = \frac{10,320 \times 48 \times 36}{4 \times 31,104} = 142 \text{ psi.}$$

In order to find the tensile and compressive stresses due to overturning, compute the moment of inertia of the net wall section with respect to its center. These calculations are listed below:

Pier	Area in.^{2}	Distance from center	L^2 in.^{2}	AL^2 in.^{4}	$I = 1/12\ AD^2$ in.^{4}	$AL^2 + I$ in.^{4}
A,D	192	120	14,400	2,760,000	9,216	2,769,216
B	288	42	1,764	507,600	31,104	538,704
C	288	30	900	259,200	31,104	290,304
Total						3,598,224

The total lateral force times the vertical distance, from this force to the plane in which stresses are being computed, equals the overturning moment. The most highly stressed section in the wall is 3 ft. above the floor level. The overturning moment in A and D,

$$\frac{MC}{I} = \frac{30{,}000 \times 108 \times 132}{3{,}598{,}224} = 119 \text{ psi.}$$

where C is the distance to the extreme fiber;

in B,

$$\frac{MC}{I} = \frac{30{,}000 \times 108 \times 60}{3{,}598{,}224} = 54 \text{ psi.}$$

in C,

$$\frac{MC}{I} = \frac{30{,}000 \times 108 \times 48}{3{,}598{,}224} = 43 \text{ psi.}$$

The compressive stress in the wall due to gravity load is assumed to be 20 psi. It should be added to the compressive stresses.

The maximum total tensile and compressive stress in piers are

$f_A = f_D = 146 + 119 = 265$ psi. (tension)

$f_A = f_D = 265 + 20 = 285$ psi. (compression)

$f_B = 143 + 54 = 197$ psi. (tension)

$f_B = 197 + 20 = 217$ psi. (compression)

$f_C = 143 + 43 = 186$ psi. (tension)

$f_C = 186 + 20 = 206$ psi. (compression).

FOOTINGS

The first step in the design of a building is to provide a rigid foundation of reinforced concrete. A continuous tied together foundation of reinforced concrete can increase the resistance of a building to lateral earthquake forces.

The effect of the overturning moment is to increase the pressure on the foundation on the B side of the building. For example, if the earthquake motion is from B to A. The soil pressure on the A side will be correspondingly reduced. However, since earthquake forces may come from any direction, static-load pressure should not be reduced.

Example:

Let us consider a one-story building of the cross-section shown in Fig. 11 to illustrate the effect of overturning moment on the foundation. The roof is of beam and slab construction. The vertical members are

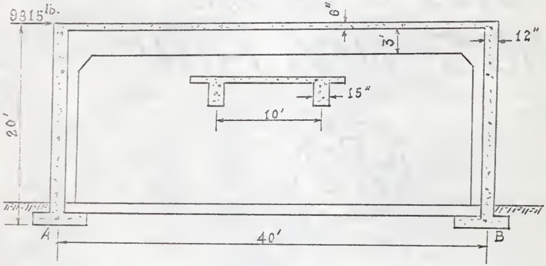

Fig. 11. Section through a one-story building.

bearing walls with pilasters. The concentrated loads of the roof beams are considered to be uniformly distributed to the foundation by the walls, acting as stiff girders.

Dead load of a 10-ft. portion is as follows:

Slab	$150 \times 0.5 \times 10 \times 41$	= 30,750 lb.
Beam	$150 \times 3 \times 1.25 \times 40$	= 22,500 lb.
Pilasters	$150 \times 1 \times 1.25 \times 7 \times 2$	= 2,600 lb.
Wall	$150 \times 1 \times 10 \times 10 \times 2$	= 30,000 lb.
Total		85,850 lb.

Live load: $30 \times 41 \times 10 = 12{,}300$ lb.

If a seismic coefficient $C = 0.1$ and k in the formula for the lateral force is taken as 1

then $F = C\,(W_d + kW_l) = 0.1\,(85{,}850 + 1 \times 12{,}300) = 9{,}815$ lb.

This force is applied in the direction shown by the arrow at the roof line of the building. If moments of the force about the footing are taken and divided by the width of the building, the additional pressure on the foundations is obtained as

$$W = \frac{9{,}815 \times 20}{40 \times 10} = 491 \text{ lb./ft.}$$

Building codes usually permit an increase in the soil pressure for combining static and seismic loads. The combined soil pressure should not exceed the normal allowable pressure plus 33 1/3 per cent.

Los Angeles and Pacific Coast building codes require buildings on piles on soil with bearing capacity less than 2,000 psf. Many building codes also require interconnection of footings as an important means of securing rigidity and a moving together of all units in the structure. Either separate struts or a solid slab can be a good foundation tie. The basement floor slab is an effective tie.

If struts are used they should completely tie all parts of the foundation in two directions approximately at right angles to each other. Each member should be capable of transmitting at least 10 per cent of the total vertical load carried by footings. The minimum gross size of the ties should be 12 in. by 12 in. and the ties should have a minimum reinforcement of four No. 5 bars with not less than No. 2 ties spaced not more than 12 in. apart.

If the reinforced concrete slab is used, building codes require the thickness to be at least 1/48 of the clear distance between the connected foundations but not less than 6 in. The reinforcement of this slab should be a minimum of 0.11 in.^{2} of steel per foot of slab in each direction.

ANALYSIS OF TWO-STORY HOUSE

The method of calculating the distribution of lateral loads and determination of stresses is typical for a reinforced concrete building and can be applied to larger structures. The example that follows is a practical application of the design principles discussed in preceding sections.

Figure 12 shows a reinforced concrete house containing basement, first and second floors, and attic.

The first step in the analysis for lateral forces is to estimate the vertical loads acting at each floor level. The dead loads should be computed for each floor from mid-story to mid-story, for the attic floor from peak of roof to mid-story, and for the basement floor from mid-story to bottom of slab. The dead loads are approximately

$$150 \times (21.4 \times 36.4 \times 0.5 + 4 \times 0.67 \times 115.3 + 65 \times 0.5 \times 4)$$

$= 125{,}000$ lb. for the basement floor and

$$150 \times (21.4 \times 36.4 \times 0.416 + 9 \times 0.67 \times 115.3 + 9 \times 65 \times 0.5)$$

$= 200{,}000$ lb. each, for first, second, and attic floors.

By Los Angeles, Pacific Coast Zone 3, and Title 21 codes for bearing walls, the lateral forces are obtained by multiplying the vertical loads by the seismic coefficient $C = 0.2$; therefore,

$P_B = 25{,}000$ lb. for basement

$P_F = 40{,}000$ lb. for first, second and attic floor.

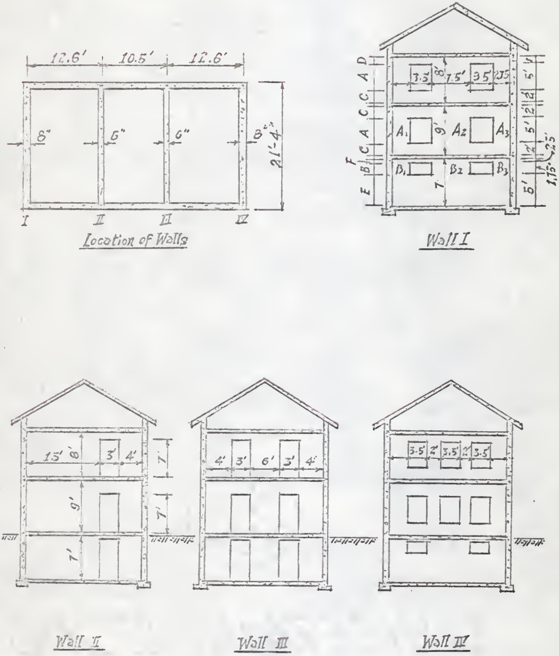

Fig. 12

A Two-Story Concrete House

We assumed that this building has been designed for vertical dead and live loads. The object of the earthquake analysis is to determine whether any increase in wall and slab thickness and in amount of reinforcement is required to resist the lateral forces.

Basement Slab:

The total weight of the building is

$$3 \times 200{,}000 + 125{,}000 + 4 \times 40\,(20 \times 34) = 834{,}000 \text{ lb.}$$

The total length of footings is 115.3 ft. and the pressure on soil will, therefore, be

$$\frac{834{,}000}{115.3} = 7{,}230 \text{ lb. per 1 in. ft. of footing .}$$

The reinforcement required in the basement slab to satisfy the requirements of foundation ties is

$$\frac{0.1 \times 7{,}230}{26{,}700} = 0.027 \text{ in.}^2$$

A minimum reinforcement of No. 3 bars spaced 9 in. will be used in both directions.

Partitions:

When the earthquake force is normal to the direction of the wall, the moment of resisting by a partition due to its own weight is $M\ 1/8\ wl^2$

$$W = 0.2 \times 75 = 15 \text{ psf.}$$

$$M = 1/8 \times 15 \times 9^2 \times 12 = 1{,}820 \text{ in.lb.}$$

If the reinforcement is placed in the center of the wall, the maximum compressive stress in concrete will approximately be

$$f_c = \frac{M}{1/6\ bd^2} = \frac{1,820}{1/6 \times 12 \times 3^2} = 101 \text{ psi.}$$

and the required steel area will be

$$A_s = \frac{M}{f_s \times 7/8 \times d} = \frac{1,820}{26,700 \times 7/8 \times 3} = 0.03 \text{ in.}^2$$

Minimum reinforcement of No. 3 bars space 7 in. is equivalent to 0.19 in.^{2}. It will be shown that when this partition acts as cross walls, additional reinforcement is required.

Cross Walls

First, compute the relative rigidities of the four cross walls, I, II, III, and IV, shown in Fig. 12. For convenience, a force of 10^6 lb. is assumed placed at the top of each wall. Deflection of parts A to E in wall I will be computed by formula

$$\Delta = \frac{1}{t}\left[0.333\left(\frac{H}{d}\right)^3 + \frac{H}{d}\right],$$

The resulting deflections are given in table below for piers of wall I

Pier	$\frac{H}{d}$	Deflection Δ	Rigidity $\frac{1}{\Delta}$	$\dfrac{1}{\frac{1}{\Delta_1}+\frac{1}{\Delta_2}+\frac{1}{\Delta_3}}$
A_1	1.816	0.477	2.09	
A_2	0.667	0.095	10.40	(A) 0.069
A_3	1.816	0.477	2.09	
B_1	0.637	0.091	11.00	
B_2	0.235	0.030	33.40	(B) 0.018
B_3	0.637	0.091	11.00	
C	0.100	0.013		0.013
D	0.050	0.006		0.006
E				0.032
F				0.002

The deflection of the wall for each story can be obtained as below by adding the deflections of the individual parts.

Basement		First floor		Second floor	
F	0.002	C	0.013	D	0.006
B	0.018	A	0.069	A	0.013
E	0.032	C	0.013	C	0.069
Total	0.052	Total	0.095	Total	0.088

The deflections of walls II, III and IV are determined in the same way as for wall I. The total deflections and relative rigidities of each wall for each story is tabulated as below.

Wall	Deflection	Rigidity	Relative rigidities
		Basement	
I	0.052	19.23	0.332
II	0.082	12.20	0.210
III	0.137	7.30	0.126
IV	0.052	19.23	0.332
		First floor	
I	0.095	10.64	0.330
II	0.099	10.08	0.311
III	0.161	6.22	0.192
IV	0.184	5.43	0.167
		Second floor	
I	0.088	11.49	0.322
II	0.091	11.00	0.317
III	0.152	6.56	0.189
IV	0.178	5.62	0.162

Find the center of rigidity for each story by using the relative rigidities as weights. The distance from wall I to the center of rigidity is as follows:

For basement walls

$$0.21 \times 12.6 + 0.126 \times 23.1 + 0.332 \times 35.7 = 17.41 \text{ ft.}$$

For first floor walls

$$0.311 \times 12.6 + 0.192 \times 23.1 + 0.167 \times 35.7 = 14.31 \text{ ft.}$$

For second floor walls

$$0.317 \times 12.6 + 0.189 \times 23.1 + 0.162 \times 35.7 = 14.15 \text{ ft.}$$

The distance between the center of mass and center of rigidity is as follows:

For basement walls,

$17.85 - 17.41 = 0.44$ ft.

For first floor walls

$17.85 - 14.31 = 3.54$ ft.

For second floor walls

$17.85 - 14.15 = 3.70$ ft.

The shearing stresses act at the top of the wall on the basement:

$P'_{I} = 40{,}000 \times 3 \times 0.332 = 39{,}840$ lb.

$P'_{II} = 40{,}000 \times 3 \times 0.210 = 25{,}200$ lb.

$P'_{III} = 40{,}000 \times 3 \times 0.126 = 15{,}120$ lb.

$P'_{IV} = 40{,}000 \times 3 \times 0.332 = 39{,}840$ lb.

The reactions on the basement wall due to the moment of the lateral load about the center of rigidity are found by solving the following equation:

$$P''_{I}\,(-17.41) + P''_{I} \times \frac{0.21}{0.332} \times \frac{(-4.81)^2}{-17.41} + P'' \times \frac{0.126}{0.332} \times \frac{5.69^2}{-17.41}$$

$$+ P''_{I} \times \frac{0.332}{0.332} \times \frac{(18.29)^2}{-17.41} = 40{,}000\,(-0.44 - 3.54 - 3.70)$$

$P''_{I} = -8{,}050$ lb.

$$P''_{II} = -8{,}050 \times \frac{0.21}{0.332} \times \frac{-4.81}{-17.41} = -1{,}410 \text{ lb.}$$

$$P''_{III} = -8{,}050 \times \frac{0.126}{0.332} \times \frac{5.69}{-17.41} = 1{,}000 \text{ lb.}$$

$$P''_{IV} = -8{,}050 \times \frac{0.332}{0.332} \times \frac{18.29}{-17.41} = 8{,}460 \text{ lb.}$$

Therefore, the design load at the first floor level on the basement walls will be:

$P_1 = 39,840$ lb.

$P_2 = 25,200$ lb.

$P_3 = 16,120$ lb.

$P_4 = 48,300$ lb.

Design loads for first and second walls, found by the same procedure, are as follows:

First floor walls	Second floor walls
$P_1 = 26,400$ lb.	$P_1 = 13,250$ lb.
$P_2 = 24,900$ lb.	$P_2 = 12,700$ lb.
$P_3 = 18,440$ lb.	$P_3 = 9,150$ lb.
$P_4 = 19,790$ lb.	$P_4 = 9,770$ lb.

As a typical example of stress determination, the stresses in wall 3 below the first floor will be computed:

Flexural and Shearing Stresses in Basement Wall 3

	(in.) Δ	$\frac{1}{\Delta}$	Relative rigidity	Lateral force (lb.)	Max, M	Flexural stress	Shearing stress
P	0.590	1.70	0.245	3,940	165,000	72	14
R	0.238	3.54	0.510	8,210	345,000	67	19
S	0.590	1.70	0.245	3,940	165,000	72	14

The total overturning moment about the bottom of the wall is computed as follows:

$$M_o = (9,150 \times 8.5 + 18,440 \times 9.5 + 16,120 \times 7.5) \times 12 = 4,490,000 \text{ in.lb.}$$

Since part of the total moment is assumed to be restricted by flexural moment, the net moment is

$$M = 4,490,000 - 675,000 = 3,810,000 \text{ in.lb.}$$

In order to determine the stress of overturning, we compute the moment of inertia of net section of the wall

$$I_n = 20,427,000 \text{ in.}^4$$

The stresses are

In Pier R

$$f_o = \frac{3,810,000 \times 36}{20,427,000} = 7 \text{ psi.}$$

Pier P and S

$$f_o = \frac{3,810,000 \times 72}{20,427,000} = \pm 13 \text{ psi.}$$

$$f_o = \frac{3,810,000 \times 120}{20,427,000} = \pm 22 \text{ psi.}$$

The stress due to gravity load is dead and live load per linear foot of pier divided by the area per linear foot of the pier

$$f_g = \frac{5,640}{72} = 79 \text{ psi.}$$

The stress diagrams for overturning, flexure and vertical load are shown in Fig. 13 (A). The stress due to vertical load should be combined only when obtaining, the maximum compressive stress.

The spacing of reinforcement will be determined for Pier S, for which stress distribution is given as Fig. 13 (B).

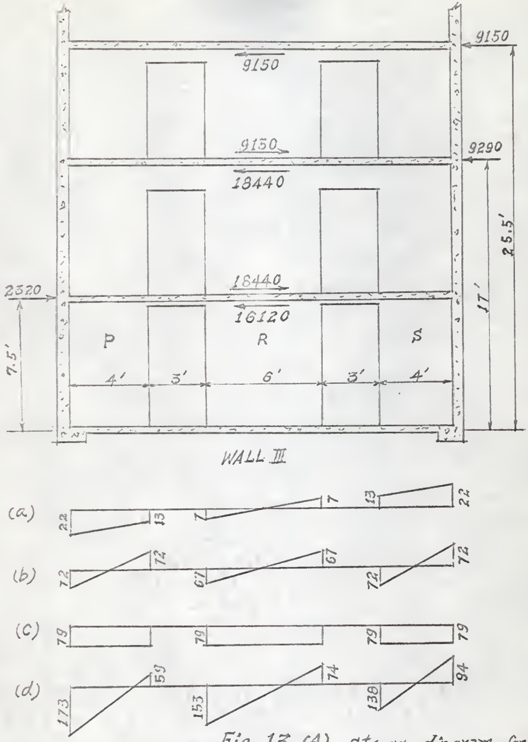

Fig. 13 (A) Stress diagram for Wall III

(a) Stresses due to overturning
(b) Stresses due to flexure
(c) Stresses due to vertical load
(d) Combined stresses

for the first second, the total tensile force is

$$\frac{564 + 282}{2} \times 9.75 = 4{,}130 \text{ lb.}$$

$$A_s = \frac{4{,}130}{26{,}700} = 0.155 \text{ in.}^2$$

which is

$$0.155 \times \frac{12}{9.75} = 0.191 \text{ in.}^2/\text{ft.}$$

No. 3 bars at 6 in.

Minimum reinforcement of No. 3 bars at 7 in. is sufficient for the other sections. But the earthquake force may be applied from the opposite direction so that the reinforcement must be arranged symmetrically about the center line of the building.

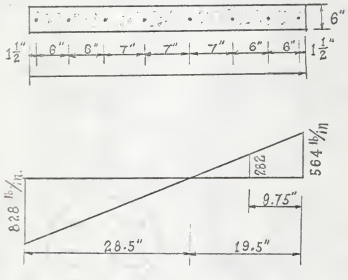

Fig. 13 (B). Stress diagram for pier S Wall III.

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BIBLIOGRAPHY

1. "Requirements of Earthquake-resistant Design," cT: 814, 815, Transactions ASCE, 1953.

2. "Earthquakes and Structures," Leander M. Hoskins and John D. Galloway, 105, 269, Transactions ASCE, 1940.

3. "Advanced Reinforced Concrete," Clarence W. Dunham, McGraw-Hill Book Company, 1964.

4. "Analysis of Small Reinforced Concrete Buildings for Earthquake Forces," Portland Cement Association, 1955.

5. "Design of Concrete Structures," George Winter, C. E. O'Rourke, and Arthur H. Nilson, 1964.

6. "Lateral Forces of Earthquake and Wind," Paper No. 2514 of the Transactions ASCE, Vol. 117, 1952.

A STUDY OF BUILDING CODE REQUIREMENTS FOR SMALL REINFORCED CONCRETE BUILDINGS SUBJECTED TO EARTHQUAKE FORCES

by

JAMES KAN-CHOU PAN

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
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The main purpose of this report was to illustrate the procedure for building a safe and economical small reinforced concrete structure capable of withstanding earthquake forces. In a concrete structure this aim can be achieved at very little, if any, added expense. This is particularly true in small buildings.

It is necessary to be familiar with the design loads and building code requirements. The following codes have been consulted:

1. Los Angeles City Building Code, 1953
2. Title 21 of California Administrative Code, 1953
3. Uniform Building Code by Pacific Coast Building Officials Conference, 1952
4. Building Code Requirements for Reinforced Concrete of American Concrete Institute (ACI 318-51)

There are slight differences between the requirements of the various codes, but in accordance with local situations they can be properly applied.

In general, an earthquake consists of horizontal and vertical ground movements or vibrations. The vertical motion is usually one-tenth to one-fifth the magnitude of the horizontal motion. The "safety factor" against failure from conventional design loads is sufficient to permit the increased stress due to vertical earth movements. The destructive force is caused by horizontal motion. The acceleration of the horizontal movement varies and its maximum value is the yardstick commonly adopted for measuring the equivalent static force.

Buildings should be designed to resist lateral forces in any direction because the motion of an earthquake may occur in any direction.

However, the earth movement can be replaced by two components acting parallel to the axes of the building; therefore, it is sufficient to investigate its strength in two perpendicular directions.

The lateral forces must be resisted by walls and by the framing system. Outside walls and partitions parallel to the direction of the earthquake motion possess much greater strength and rigidity against distortion than those normal to this direction.

Some experimental results are presented to demonstrate how to prevent the cracks that occur in floors at the corners, and around openings in floor slabs.

Separate discussions on parapet walls, bearing walls, floors, footings, cross walls, and an analysis of a two-story house are presented in this report.