SALT LAKE CITY SCHOOLS
ESTIMATES OF DEATH AND INJURY
DURING SEISMIC GROUND SHAKING

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Introduction

The Board of Education of the Salt Lake City School District authorized a study of the seismic vulnerability of each of the schools in the district. Once this study was completed, the board appointed a seismic study committee made up of a broad spectrum of citizens to make recommendations to them as to what actions should be taken to mitigate the potential life and property losses associated with an earthquake. The study committee met during the fall of 1989 and submitted its report on December 20, 1989. This paper deals with the portion of the overall seismic study committee report that estimated the number of deaths and injuries that might be expected if an earthquake occurred when school was in session. These estimates were based on the expected performance of the buildings as determined in the previous seismic vulnerability study.

Local Seismicity

Salt Lake City is sited on the west face of the Wasatch Mountain Range in a valley that marks the transition zone from the mountain country on the east and the desert expanses to the west. A major earthquake fault parallels the west face of the Wasatch mountains and extends from Nephi on the south to the Idaho border on the north. The Wasatch fault is part of a larger system of faulting termed the Intermountain Seismic Zone.

The Wasatch fault has an approximate length of 238 miles and has been determined to consist of ten individual segments. Geologic trenching studies have determined that a segment of the fault has moved seventeen times during the last 6,000 years Based upon these studies, it has been determined that one of the individual segments of the fault will slip every 340 to 415 years with an average Richter magnitude of 7.2 to 7.5. The Wasatch fault represents the major source of potential ground shaking in the Salt Lake Valley but is not the only source. There are other fault systems in the valley and in the mountains to the east and west that could produce building damaging ground motion Recent studies of this local seismicity has lead to a better understanding of the potential for ground shaking that exists and for the losses that would result. This increased understanding and awareness in the community resulted in the decision by the Salt Lake School Board to conduct the seismic studies

Building Inventory

Prior to the special seismic study committee's work, the staff of Reaveley Engineers completed a seismic vulnerability assessment of forty-two individual schools and administrative facilities that comprise the building inventory of the Salt Lake School District. Table I is a summary of the study. The table lists the school name, the area, the estimated total costs to retrofit the buildings and the dollars to retrofit the buildings according to the segments of the individual buildings as ranked good, fair, poor, or very poor. These projected costs were for the structural portion of the work only, and were projected as costs that would need to be incurred to provide a minimum level of safety Extensive damage and some minimal loss of life might still occur.

Each building or portion of the building had been assigned a vulnerability ranking of good, fair, poor or very poor on the assessment of its expected performance in strong ground shaking. These assessments were made after utilizing the methodology presented in ATC-14. This methodology is based on the premise that the majority of buildings can be identified as belonging to one of 15 different structural system types. Figure 1 through Figure 13 are sketches of most of these basic building types (ATC-21). These basic building categories were previously used in the ATC-13 study which presented a series of damage/loss estimates for the different types of buildings. Table 3 is from ATC-21 also, and lists the various building types.

Past earthquakes have demonstrated that certain building types of older age are more vulnerable to earthquakes and are, therefore, more dangerous to be in and around when the ground is shaking. Specifically, load bearing, unreinforced masonry, non-ductile concrete frames, tilt-up concrete construction, precast, concrete buildings, and steel and concrete frames with unreinforced masonry infill walls have demonstrated their vulnerability Other building types can also be hazardous, but for the most part have been found to be less dangerous.

Specific building configuration characteristics when present can dramatically increase the amount of damage and potential for collapse. Figure 14 and Figure 15 are sketches that demonstrate some specific characteristics that can contribute to poor performance. The following are broad categories that have been shown to be potential problems:

- Horizontal torsion in seismic system resistance
- Horizontal plan irregularities
- Soft stories
- Discontinuous shear walls
- Vertical variations in cladding systems
- Vertical set backs
- Strong beam weak column systems

In many ways these configuration characteristics are as important as the basic lateral force resisting system in determining the amount of damage and injury one might expect in a specific building. The ATC-21 document, "Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Hand Book" reflects this in the methodology presented therein. All of these factors were considered when developing the ratings for the buildings listed in Table I

Student Population

The official student population in the Salt Lake City School District was 25,012 during the fall of 1989. With this number of students in the buildings on any given day, the study committee wanted to know what percentage of the students were in the different categories of buildings. Mr. Steven Harmon, Director of Facilities for the district prepared a series of tables which showed for each school how many students would be expected to be in each segment of each school during any hour of an average day. These numbers were accumulated for the various ratings and represented as Table II. The students were assumed to be in a normal classroom session, therefore, some of the building segments were assumed to be unoccupied for the injury/death study. The results of this decision shows up in Table II where there are only 23 students listed as being in buildings rated "Fair"

Estimates of Death and Injury

The request that estimates of death and injury be provided was met with considerable apprehension To project these numbers, it was felt that this could only be done on a best guess basis This guess was based on experience gained from observing earthquake damage first hand, from reading earthquake reports, and from reviewing the estimates contained in ATC-13. It was requested that the estimates been given for Richter earthquake magnitudes of 6.2 and 7.4 considering an earthquake on the Salt Lake segment and on the two adjacent segments of the Wasatch fault. Table 4 and Table 7 list the percentage of deaths and injuries that were projected for this particular set of buildings. As can be seen from the tables, the estimates are very high

Earthquakes on the Salt Lake segment would be directly under the city. The adjacent segments of the fault are between 10 miles and 30 miles away from the majority of the buildings and would, therefore, have a reduction in ground shaking intensity due to the attenuation that takes place as the wave passes through the earth. These effects were somewhat compensated for in the estimates.

The primary factors that were considered in making the estimates were.

A. The basic vulnerability

B. The number of stories in the structure

C The construction type and weight of the buildings

These factors are not independent and must be considered together when attempting estimates of this type. The vulnerability assessment provided the variation in the probability of collapse. The number of stories provided an element of total mass that might land on an individual. Whether the roof structure was concrete or of lighter construction, such as wood or steel framing, influenced the decision The three story buildings in this set of buildings all have concrete roof structures. The majority of the floors are constructed out of concrete. Tables 5 and 6 are the actual estimates of injury and death in numbers of students based upon the population of students.

Results of the studies

The seismic study committee, which had a broad based community representation, concluded that the number of injuries or deaths was unacceptable for the community to accept The committee made strong recommendations to the school board to reduce the hazard to which the students were exposed. The recommendations were to eliminate the gross problem over a twenty-year period The three-story most hazardous buildings were to be fixed or replaced within a five-year period. Between that point and the twenty year time mark there is to be a steady reduction of the hazardous buildings that were rated as poor or very poor.

TABLE I

SALT LAKE SCHOOL DISTRICT
SEISMIC VULNERABILITY ASSESSMENT - COSTS
DECEMBER 20, 1989

	SCHOOL	$ PER SCHOOL	$/SQ FT	TOTAL SQ FT	SF/GOOD	SF/FAIR	SF/POOR	SF/VERY POOR
104	BACKMAN	$404,278	$9.21	43,900	4,700	0	39,200	0
108	BEACON HEIGHTS	$733,760	$13.61	53,900	7,000	0	0	46,900
204	BENNION	$0	$0.00	64,181	11,732	52,449	0	0
112	BONNEVILLE	$605,300	$10.89	55,574	0	10,464	11,310	33,800
124	DILWORTH	$233,800	$7.40	31,602	3,200	0	28,402	0
132	EDISON	$560,000	$12.12	46,200	8,800	0	0	37,400
136	EMERSON	$0	$0.00	62,300	62,300	0	0	0
144	ENSIGN	$0	$0.00	52,000	52,000	0	0	0
148	FRANKLIN	$591,000	$12.42	47,600	8,200	0	2,400	37,000
176	HAWTHORNE	$0	$0.00	63,000	63,000	0	0	0
180	HIGHLAND PARK	$1,393,000	$10.00	139,300	0	0	139,300	0
184	INDIAN HILLS	$747,460	$14.37	52,020	4,600	0	47,420	0
188	JACKSON	$0	$0.00	48,000	48,000	0	0	0
196	LINCOLN	$92,400	$1.32	70,000	0	70,000	0	0
206	LOWELL	$633,600	$12.00	52,800	0	0	52,800	0
216	MEADOWLARK	$74,000	$1.32	56,000	0	56,000	0	0
160	MOUNTAIN VIEW	$353,808	$7.22	49,040	7,440	0	41,600	0
220	NEWMAN	$412,153	$9.17	44,950	4,700	0	40,250	0
224	NIBLEY PARK	$654,380	$15.01	43,590	7,130	0	36,460	0
242	PARKVIEW	$778,000	$10.34	75,250	23,250	0	0	52,000
244	RILEY	$589,000	$13.73	42,900	6,100	0	0	36,800
252	ROSE PARK	$736,000	$14.06	52,360	5,788	1,600	0	44,972
256	ROSSLYN HEIGHTS	$554,875	$11.61	47,800	5,900	0	8,500	33,400
268	UINTAH	$570,175	$11.02	51,720	0	5,200	0	46,520
272	WASATCH	$0	$0.00	54,000	54,000	0	0	0
276	WASHINGTON	$185,000	$3.15	58,776	42,000	0	16,776	0
288	WHITTIER	$815,500	$14.43	56,500	0	0	0	56,500
404	BRYANT	$7,000	$0.06	114,000	114,000	0	0	0
408	CLAYTON	$1,917,000	$18.69	102,575	575	0	102,000	0
412	GLENDALE	$2,036,000	$17.25	118,050	2,700	0	115,350	0
416	HILLSIDE	$1,318,000	$6.51	202,400	0	5,400	197,000	0
440	NORTHWEST	$1,779,000	$16.87	105,450	1,600	3,850	100,000	0
704	EAST	$3,426,250	$8.70	393,700	67,000	0	71,700	255,000
708	HIGHLAND	$1,936,460	$6.63	292,216	54,600	0	28,978	208,638
716	WEST	$2,122,938	$5.20	408,404	72,534	78,000	0	257,870
750	SALT LAKE COMM. HIGH	$900,844	$10.04	89,740	0	0	89,740	0
116	COLUMBUS	$278,027	$6.74	41,254	15,474	7,780	18,000	0
212	MATHESON	$373,590	$10.36	36,075	0	0	36,075	0
511	GARFIELD	$471,238	$15.20	31,010	2,400	1,050	0	27,560
285	DOUGLAS	$310,158	$9.16	33,860	0	0	33,860	0
556	MAINTENENCE SHOP	$784,300	$12.94	60,600	0	17,820	42,780	0
536	AD BUILDING.	$598,270	$8.63	69,297	960	47,424	0	20,913
TOTALS		29,976,564	$8.75	3,613,894	761,683	357,037	1,299,901	1,195,273

DEFINITIONS:
GOOD - Would not significantly jeopardize life
FAIR - Low Life Hazards
POOR - Appreciable Life Hazards
VERY POOR - High Life Hazards

TABLE II

NUMBER OF STUDENTS AT RICK IN
SALT LAKE CITY SCHOOLS

Risk Category of Building	Number of Stories	Number of Students	Percentage of Students
High Life Risk (Very Poor)	3 2 1	3,904 2,201 3,033	15.61 8.80 12.13
Appreciable Life Risk (Poor)	3 2 1	558 4,222 4,888	2.32 16.88 19.54
Low Life Risk (Fair)	N/A	23	0.09
Minimal Life Risk (Good)	N/A	6,183	24.72

TABLE III

Structural Type Identifier	General Description
W	Wood buildings of all types
S1	Steel moment resisting frames
S2	Braced steel frames
S3	Light metal buildings
S4	Steel frames with cast-in-place concrete shear walls
C1	Concrete moment resisting frames
C2	Concrete shear wall buildings
C3/S5	Concrete or steel frame buildings with unreinforced masonry infill walls
TU	Tilt-up buildings
PC2	Precast concrete frame buildings
RM	Reinforced masonry
URM	Unreinforced masonry

Figure 2-6 Combinations of materials in structural types (after ATC, 1987).

TABLE 4

PERCENTAGE OF DEATHS AND INJURIES

BASED UPON BUILDING TYPE AND EARTHQUAKE ORIGIN

NOTE: THESE PERCENTAGES ARE BASED UPON THE BEST ASSESSMENT OF LARRY REAVELEY AND JIM TINGEY.

RISK CATEGORY	NUMBER OF STORIES	MODERATE EARTHQUAKE ORIGIN (6.2 RICHTER OF BIGGER)					
		SALT LAKE SEGMENT			ADJOINING SEGMENT		
		DEATHS	INJURIES	WALK AWAY	DEATHS	INJURIES	WALK AWAY
HIGH LIFE RISK (VERY POOR)	3	40%	40%	20%	20%	25%	55%
	2	15%	55%	30%	10%	35%	55%
	1	10%	40%	50%	8%	27%	65%
APPRECIABLE LIFE RISK (POOR)	3	15%	48%	37%	10%	35%	55%
	2	8%	42%	50%	6%	32%	62%
	1	6%	32%	62%	3%	21%	76%
LOW LIFE RISK (FAIR)	N/A	1.0%	4.0%	95%	0.2%	2.0%	97.8%
MINIMAL LIFE RISK (GOOD)	N/A	0.2%	2.0%	97.8%	0.1%	1.0%	98.9%

12/20/89

TABLE 5

NUMBER OF STUDENTS AT RISK IN SCHOOL BUILDINGS

BASED ON A TYPICAL SCHOOL DAY EXPOSURE

RISK CATEGORY	NUMBER OF STORIES	# OF STUDENTS / % OF STUDENTS	MODERATE EARTHQUAKE ORIGIN (6 2 RICHTER OF BIGGER)					
			SALT LAKE SEGMENT			ADJOINING SEGMENT		
			DEATHS	INJURIES	WALK AWAY	DEATHS	INJURIES	WALK AWAY
HIGH LIFE RISK (VERY POOR)	3	3.904 / 15.61%	1562	1562	781	781	976	2147
	2	2.201 / 8 80%	330	1211	660	220	770	1211
	1	3.033 / 12.13%	303	1213	1517	243	819	1971
APPRECIABLE LIFE RISK (POOR)	3	558 / 2 23%	84	268	206	56	195	307
	2	4.222 / 16 88%	338	1773	2111	253	1351	2618
	1	4.888 / 19.54%	293	1564	3031	147	1026	3715
LOW LIFE RISK (FAIR)	N/A	23 / .09%	0	1	22	0	0	23
MINIMAL LIFE RISK (GOOD)	N/A	6.183 / 24 72%	12	124	6047	6	62	6115
	TOTALS	25.012	2922	7715	14375	1706	5199	18107
	% OF DISTRICT		12%	31%	57%	7%	21%	72%

Salt Lake City School District
Matrix #2

TABLE 6

BASED ON A TYPICAL SCHOOL DAY EXPOSURE

RISK CATEGORY	NUMBER OF STORIES	# OF STUDENTS / % OF STUDENTS	LARGE EARTHQUAKE ORIGIN (7.4 RICHTER OF BIGGER)					
			SALT LAKE SEGMENT			ADJOINING SEGMENT		
			DEATHS	INJURIES	WALK AWAY	DEATHS	INJURIES	WALK AWAY
HIGH LIFE RISK (VERY POOR)	3	3,904 / 15.61%	1952	1562	390	1562	1562	780
	2	2,201 / 8 80%	550	1321	330	330	1211	660
	1	3,033 / 12 13%	455	1668	910	303	1213	1517
APPRECIABLE LIFE RISK (POOR)	3	558 / 2 23%	112	307	140	84	268	206
	2	4,222 / 16 88%	507	2322	1393	338	1773	2111
	1	4,888 / 19.54%	391	2053	2444	293	1564	3031
LOW LIFE RISK (FAIR)	N/A	23 / .09%	0	2	20	0	1	22
MINIMAL LIFE RISK (GOOD)	N/A	6,183 / 24 72%	31	495	5657	12	124	6047
	TOTALS	25,012	3998	9730	11284	2922	7716	14374
	% OF DISTRICT		15.98%	38.90%	45.11%	11.68%	30.85%	57.47%

12/20/89

TABLE 7

PERCENTAGE OF DEATHS AND INJURIES

BASED UPON BUILDING TYPE AND EARTHQUAKE ORIGIN

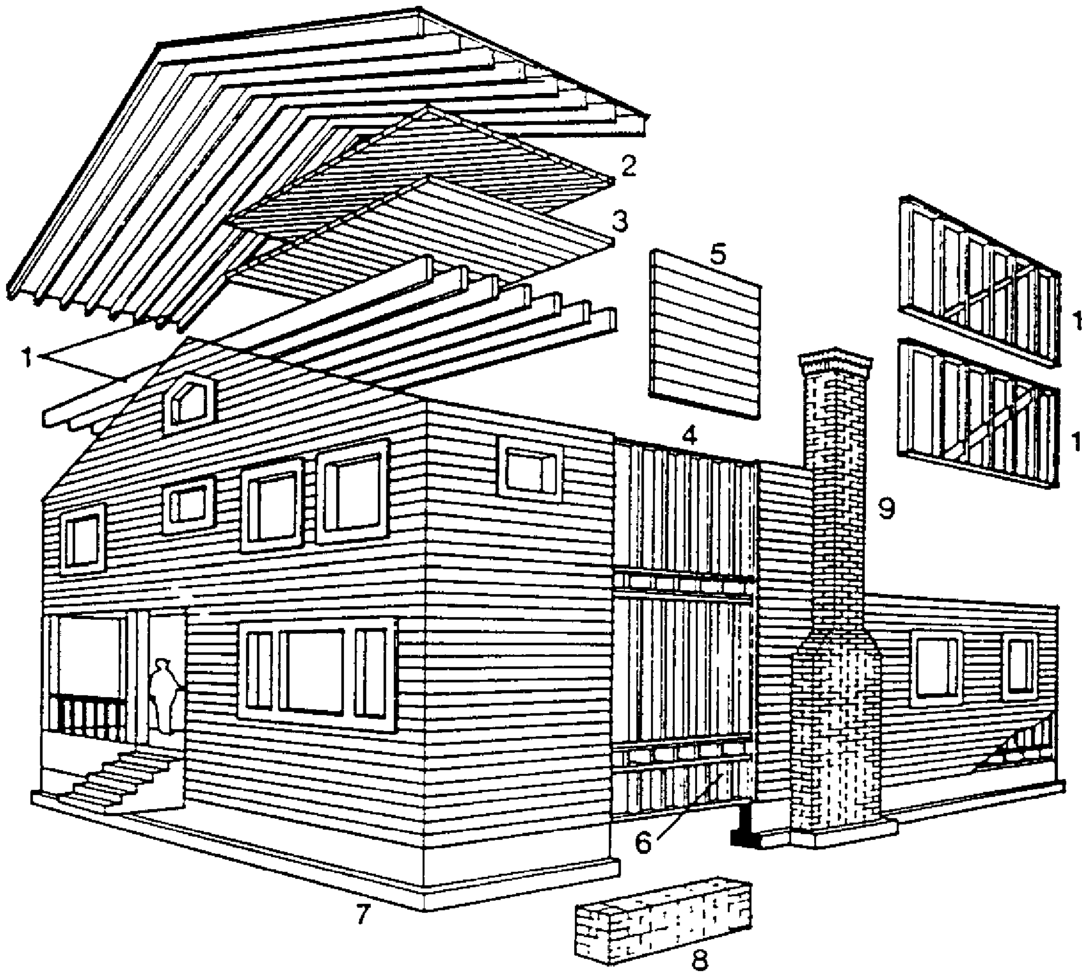
NOTE: **THESE PERCENTAGES ARE BASED UPON THE BEST ASSESSMENT OF LARRY REAVELEY AND JIM TINGEY.**

RISK CATEGORY	NUMBER OF STORIES	LARGE EARTHQUAKE ORIGIN (7 4 RICHTER OF BIGGER)					
		SALT LAKE SEGMENT			ADJOINING SEGMENT		
		DEATHS	INJURIES	WALK AWAY	DEATHS	INJURIES	WALK AWAY
HIGH LIFE RISK (VERY POOR)	3	50%	40%	10%	40%	40%	20%
	2	25%	60%	15%	15%	55%	30%
	1	15%	55%	30%	10%	40%	50%
APPRECIABLE LIFE RISK (POOR)	3	20%	55%	25%	15%	48%	37%
	2	12%	55%	33%	8%	42%	50%
	1	8%	42%	50%	6%	32%	62%
LOW LIFE RISK (FAIR)	N/A	2%	10%	88%	1.0%	4.0%	95%
MINIMAL LIFE RISK (GOOD)	N/A	0.5%	8%	91.5%	0.2%	2.0%	97.8%

12/20/89

Roof/floor span systems:
1. wood joist and rafter
2. diagonal sheathing
3. straight sheathing

Wall systems:
4. stud wall (platform or balloon framed)
5. horizontal siding



Foundation/ connections:
6. unbraced cripple wall
7. concrete foundation
8. brick foundation

Bracing and details:
9. unreinforced brick chimney
10. diagonal blocking
11. let-in brace (only in later vintages)

Figure 2-7 Wood stud frame construction

Figure 1

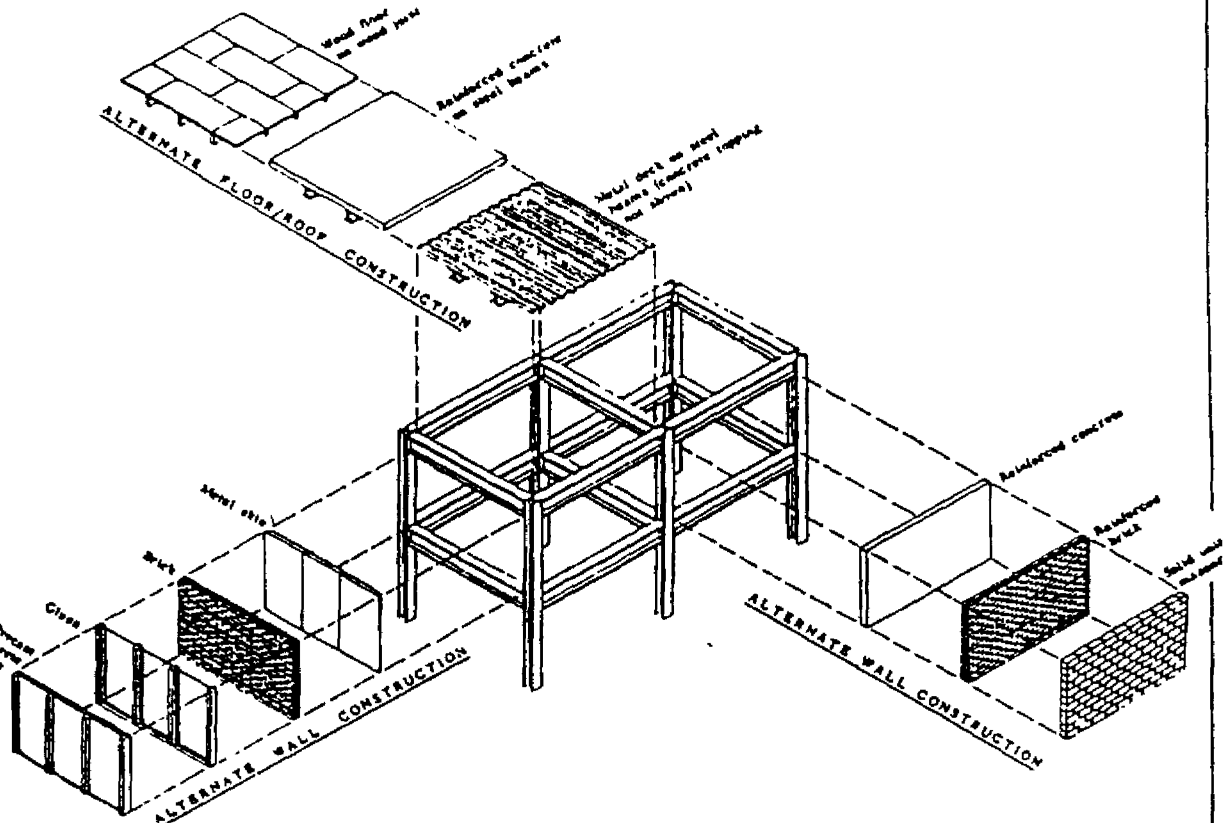


Figure 2-9 Steel moment resisting frame

Figure 2

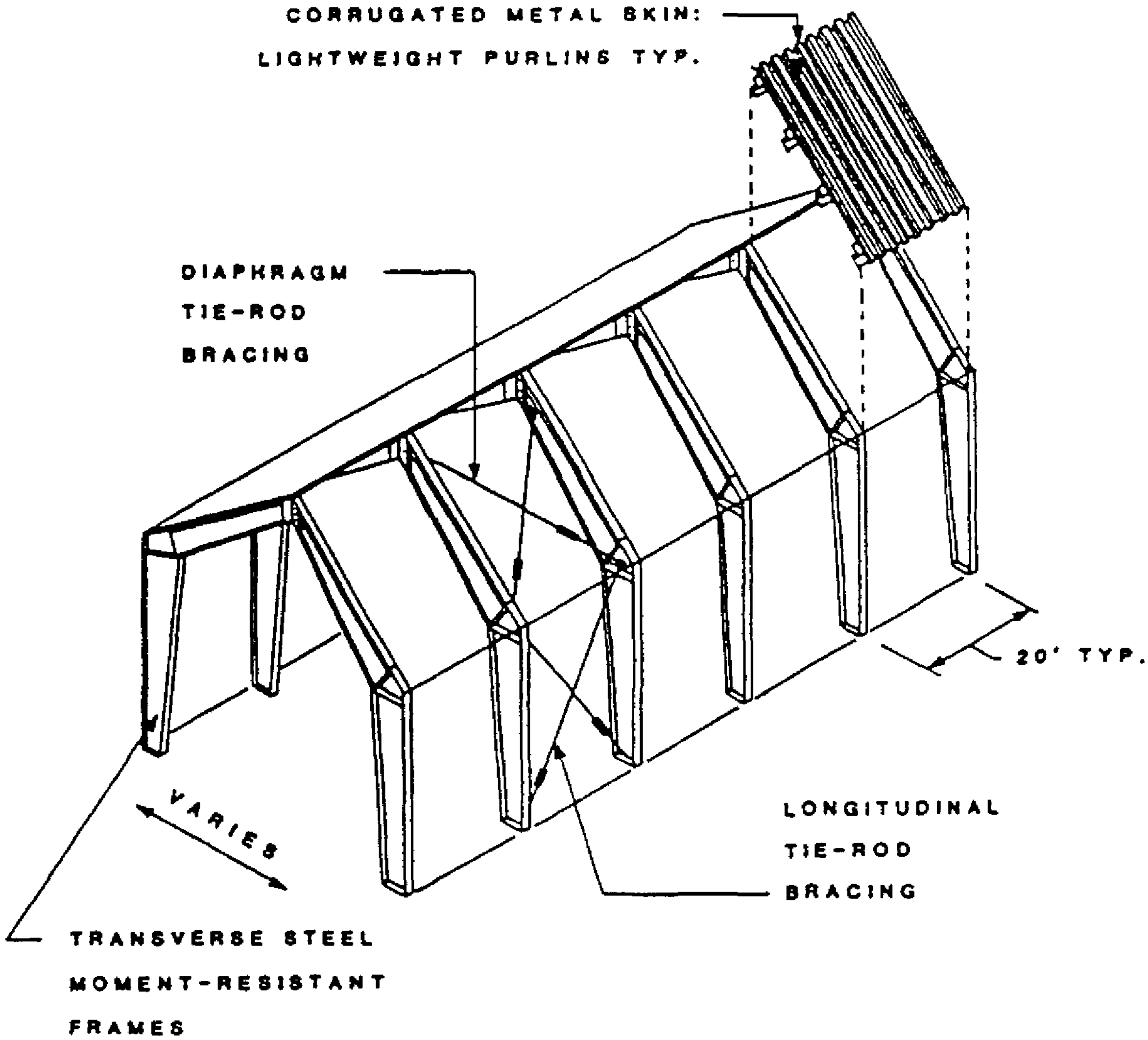


Figure 2-11 Light metal construction

Figure 3

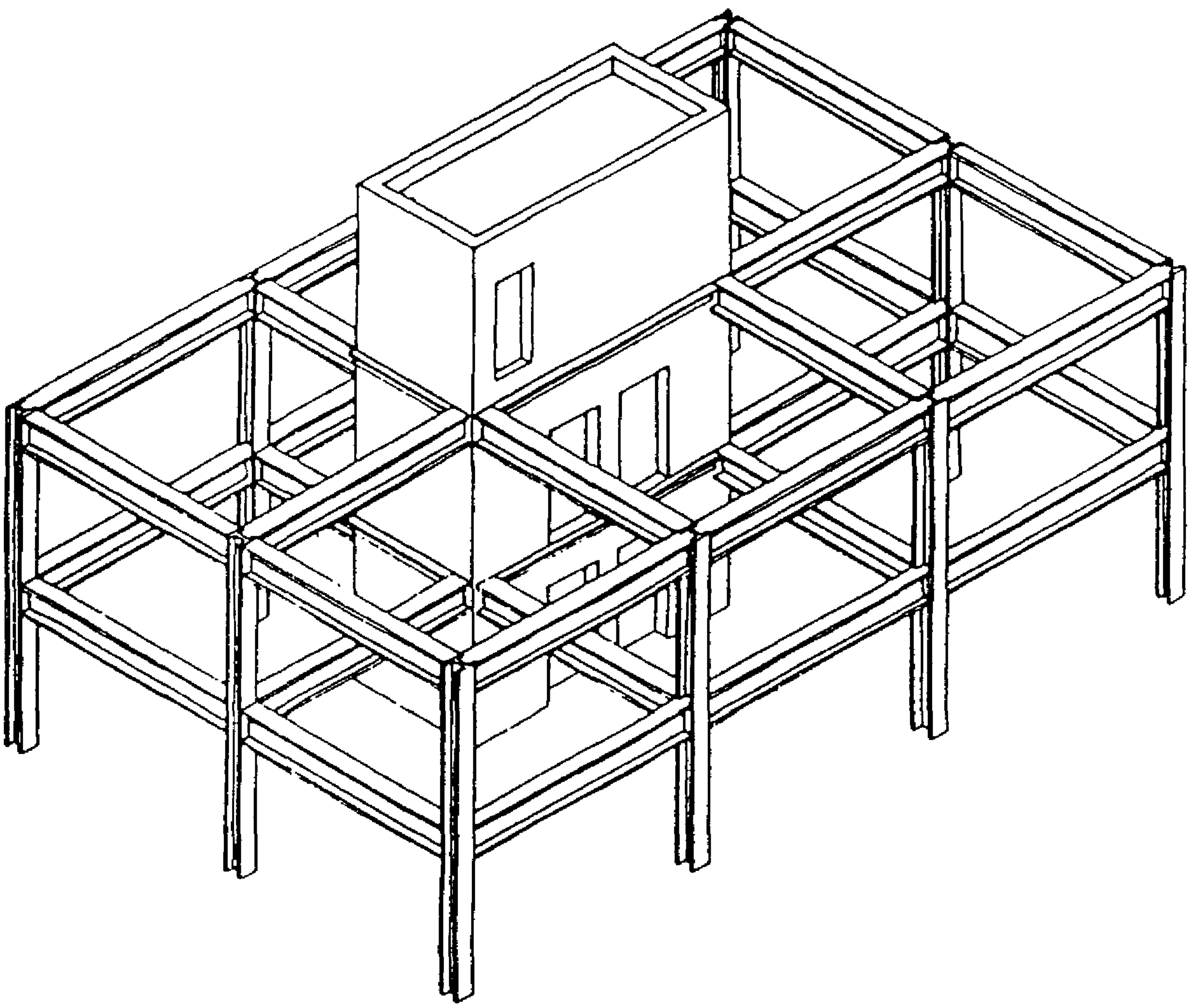
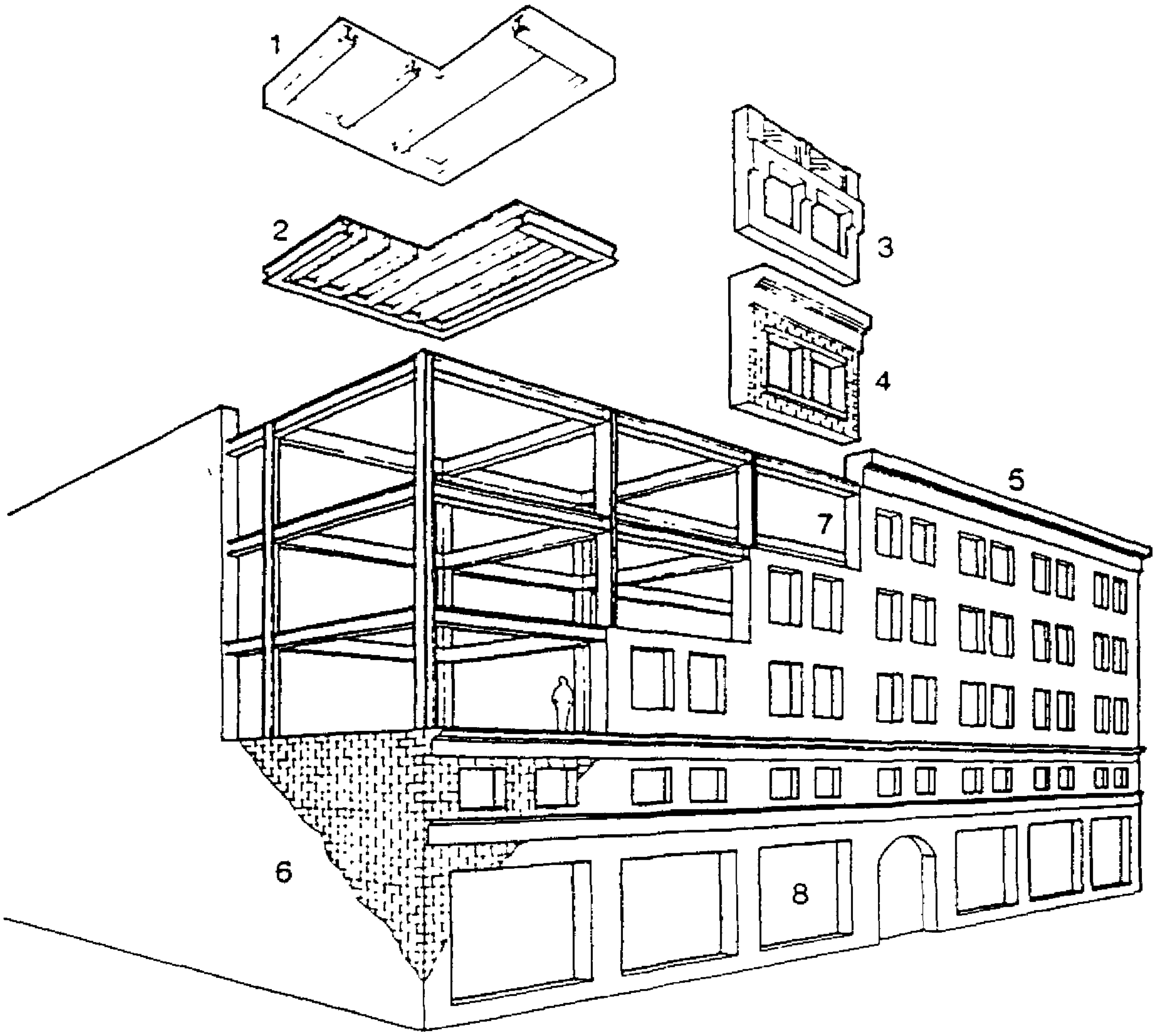


Figure 2-12 Steel frame with shear wall

Figure 4

Roof/floor span systems:
1. steel framing with concrete cover
2. wood floor joist and diaphragm (diagonal and straight)

Wall systems:
3. non-load-bearing concrete wall
4. non-load-bearing unreinforced masonry cover wall



Details:
5. unreinforced and unbraced parapet and cornice
6. solid party walls

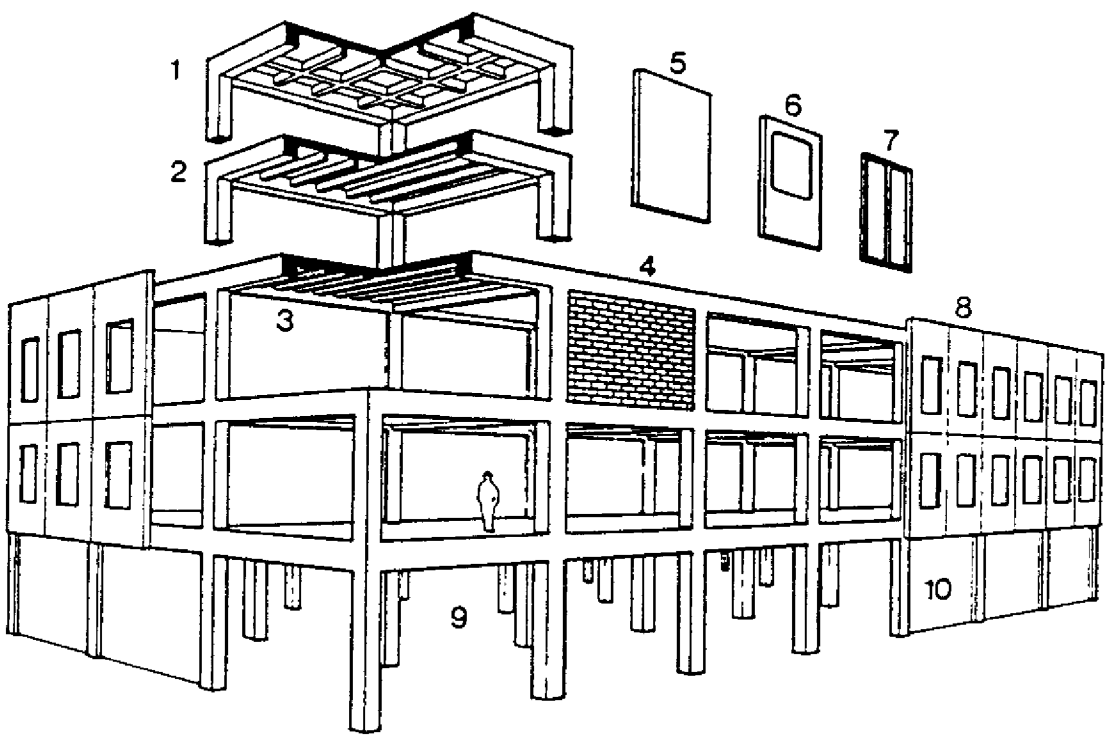
Openings and wall penetrations:
7. window penetrated front facade
8. large openings of street level shops

Figure 2-13 Steel frame with URM infill

Figure 5

Roof/floor diaphragms:
1. concrete waffle slab
2. concrete joist and slab
3. steel decking with concrete topping

Curtain wall/ non-structural infill:
4. masonry infill walls
5. stone panels
6. metal skin panels
7. glass panels
8. precast concrete panels



Structural system:
9. distributed concrete frame

Details:
10. typical tall first floor (soft story)

Figure 2-14a Concrete moment resisting frame

Figure 6

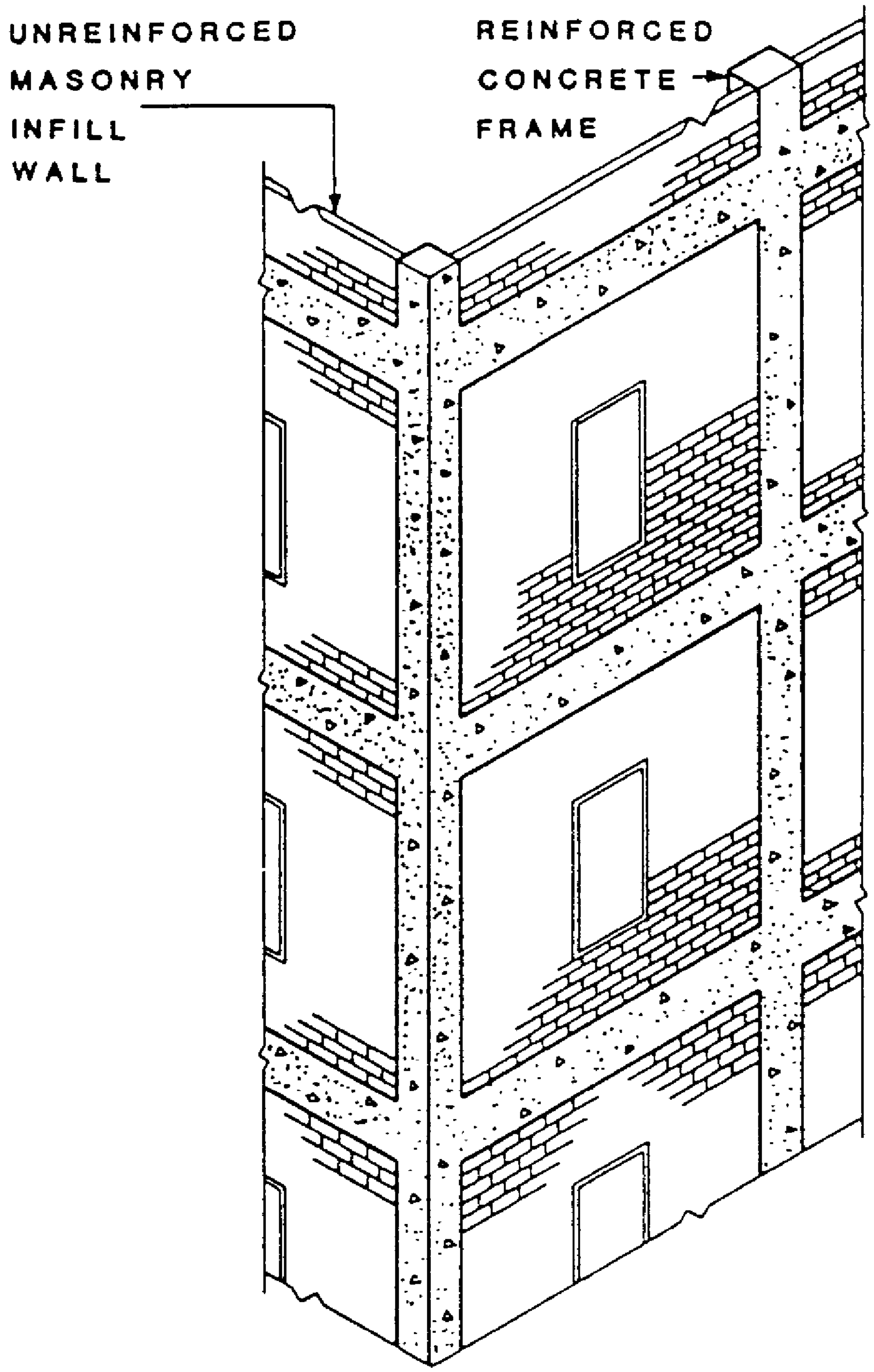


Figure 2-14b Concrete frame with URM infill

Figure 7

Roof/floor span systems:
1. heavy timber rafter roof
2. concrete joist and slab
3. concrete flat slab

Wall system:
4. interior and exterior concrete bearing walls
5. large window penetrations of school and hospital buildings

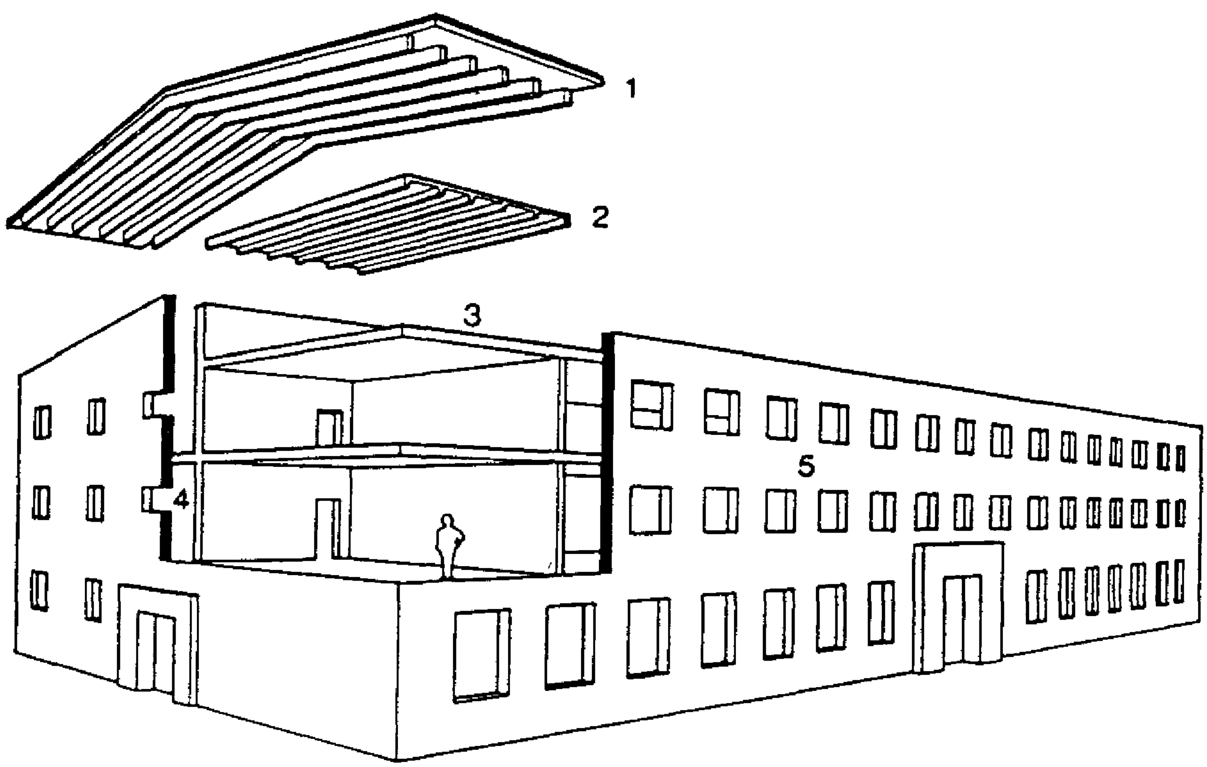
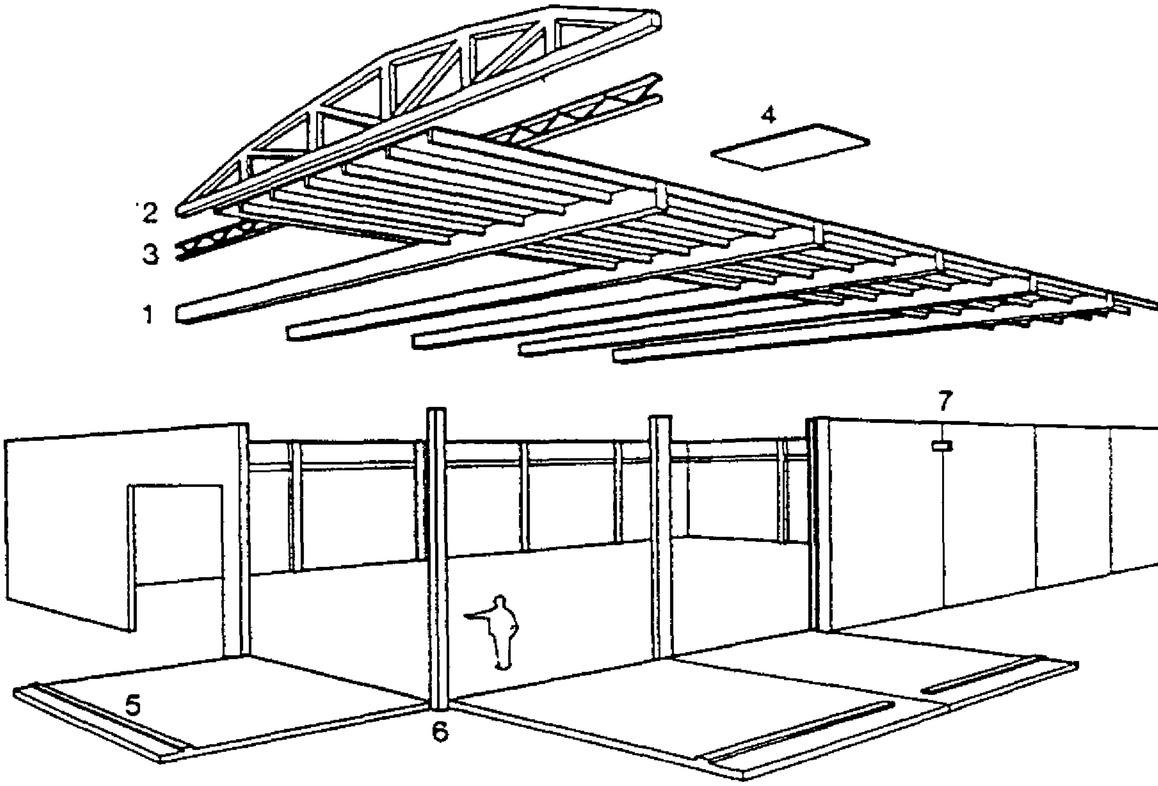


Figure 2-15 Concrete shear wall

Figure 8

Roof/floor span systems:
1. glue liminated beam and joist
2. wood truss
3. light steel -web joist

Roof/floor diaphragms:
4. plywood sheathing



Details:
5. anchor bolted wooden ledger
for roof/floor support

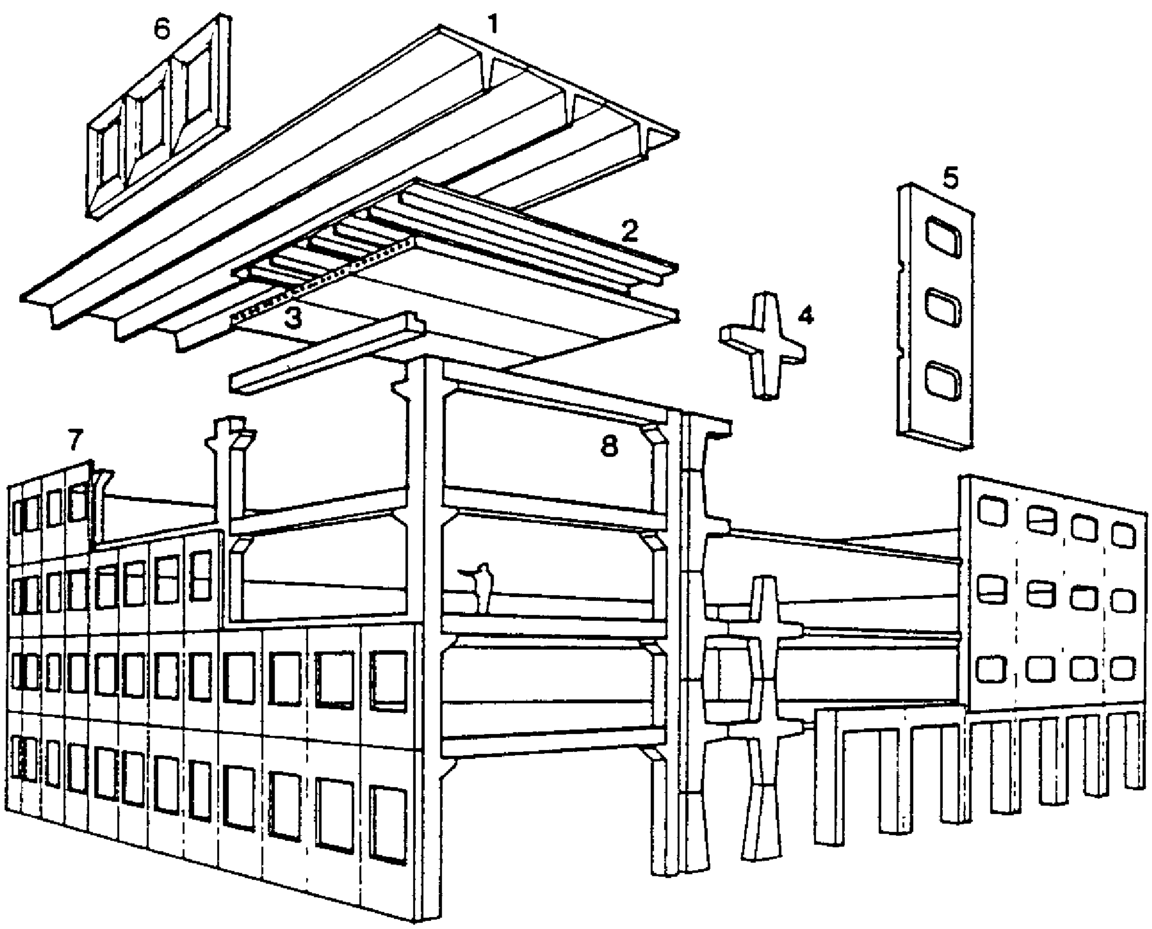
Wall systems:
6. cast-in-place columns--
square, "T" shape, and "H" shape
7. welded steel plate type panel connection

Figure 2-16 Tilt-up construction typical of the western United States.
Tilt-up construction in the eastern United States may incorporate a steel frame.

Figure 9

Roof/floor span systems:
1. structural concrete "T" sections
2. structural double "T" sections
3. hollow core concrete slab

Wall systems:
4. load-bearing frame components (cross)
5. multi-story load-bearing panels



Curtain wall system:
6. precast concrete panels
7. metal, glass, or stone panels

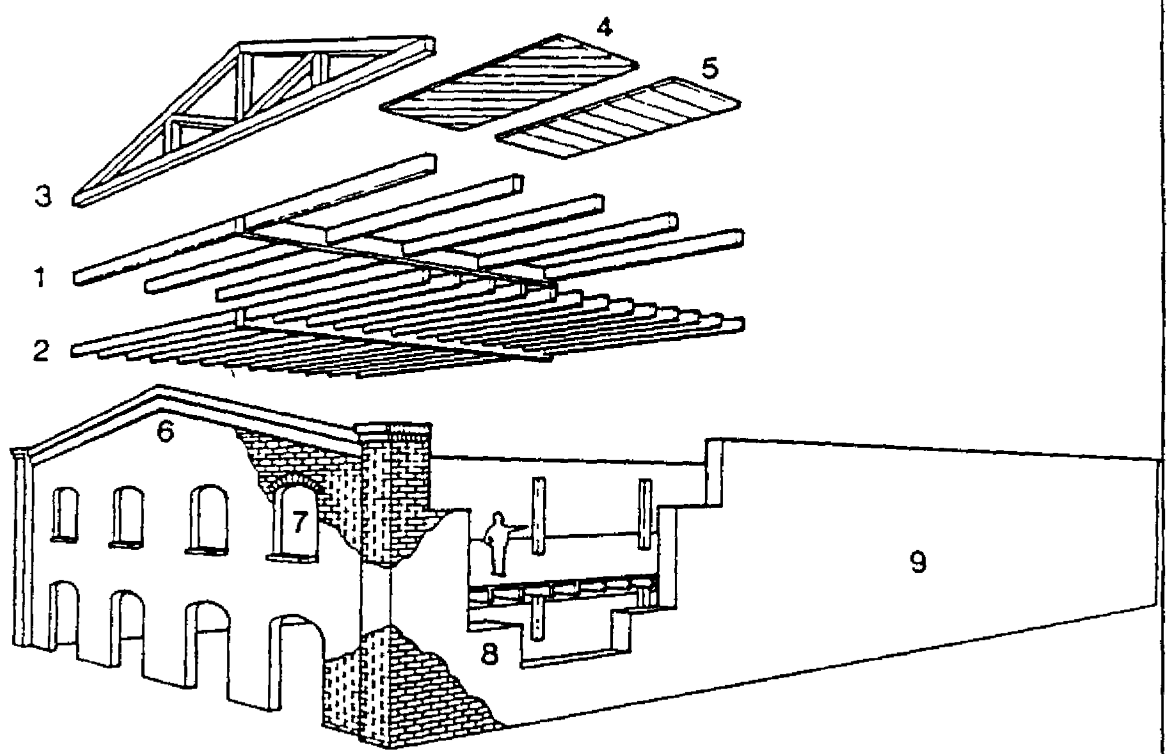
Structural system:
8. precast column and beams

Figure 2-17 Precast concrete frame

Figure 10

Roof/floor span systems:
1. wood post and beam (heavy timber)
2. wood post, beam, and joist (mill construction)
3. wood truss– pitch and curve

Roof/floor diaphragms:
4. diagonal sheathing
5. straight sheathing



Details:
6. typical unbraced parapet and cornice
7. flat arch window opennings

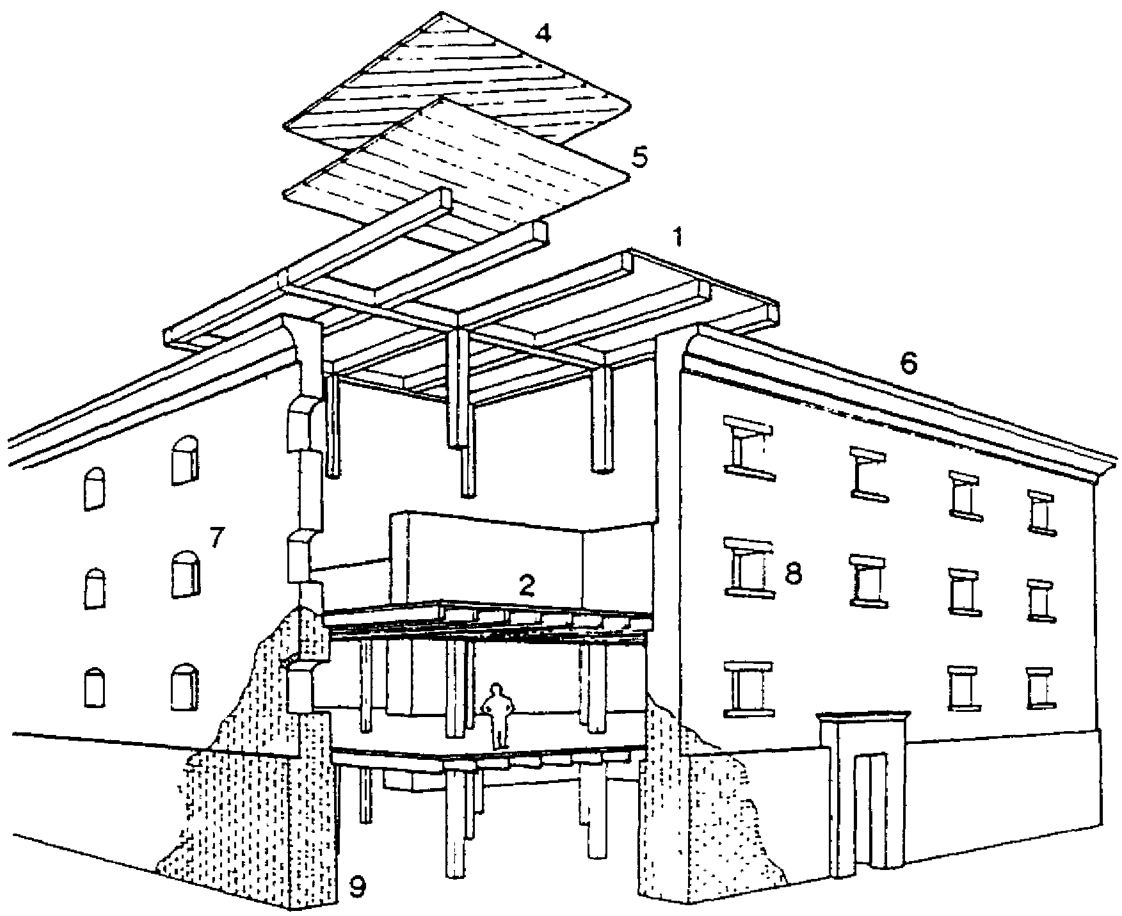
Wall systems:
8. bearing wall– four or more wythes of brick
9. typical long solid party wall

Figure 2-19a Unreinforced masonry bearing wall

Figure 11

Roof/floor span systems:
1. wood post and beam (heavy timber)
2. wood post, beam, and joist (mill construction)
3. wood truss-- pitch and curve

Roof/floor diaphragms:
4. diagonal sheathing
5. straight sheathing



Details:
6. typical unbraced parapet and cornice
7. flat arch window opennings
8. small window penetrations (if bldg is originally a warehouse)

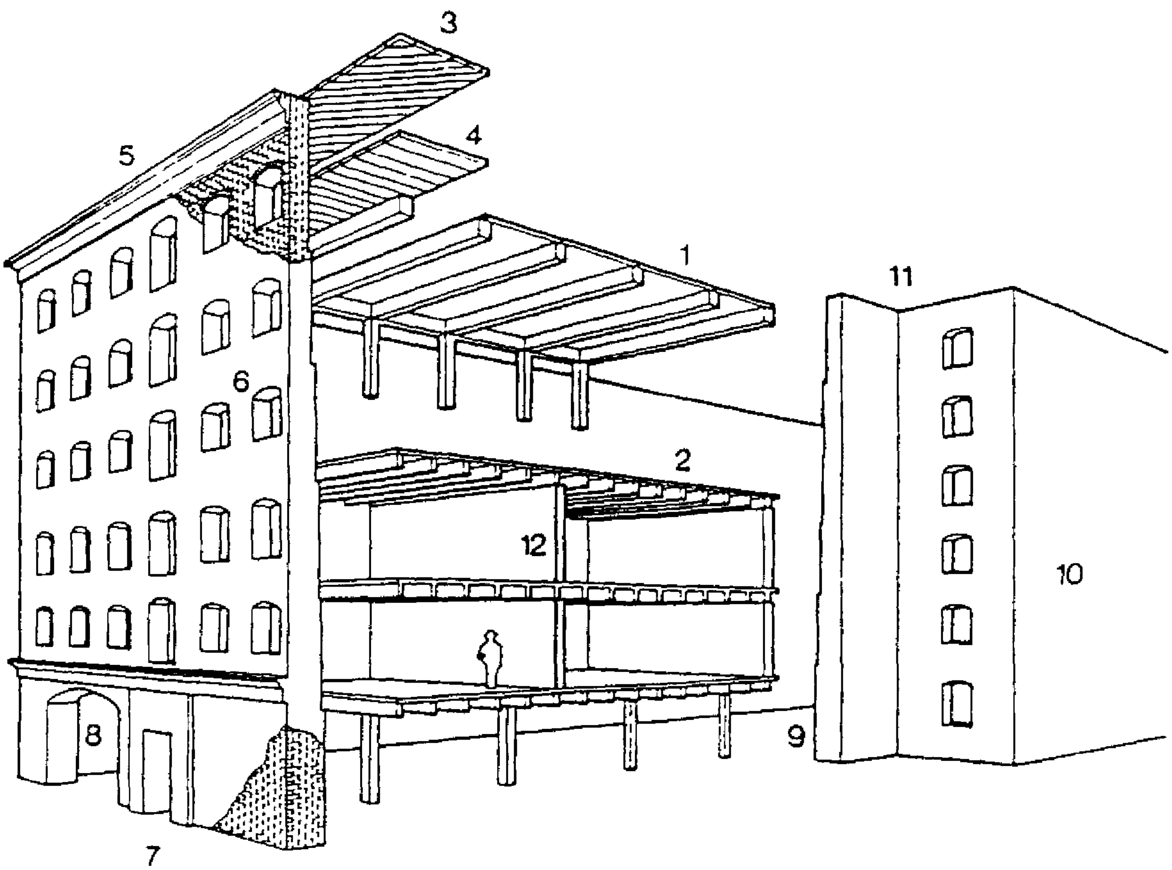
Wall systems:
9. bearing wall-- four to eight wythes of brick

Figure 2-19b Unreinforced masonry bearing wall

Figure 12

Roof/floor span systems:
1. wood post and beam (heavy timber)
2. wood post, beam, and joist (mill construction)

Roof/floor diaphragms:
3. diagonal sheathing
4. straight sheathing

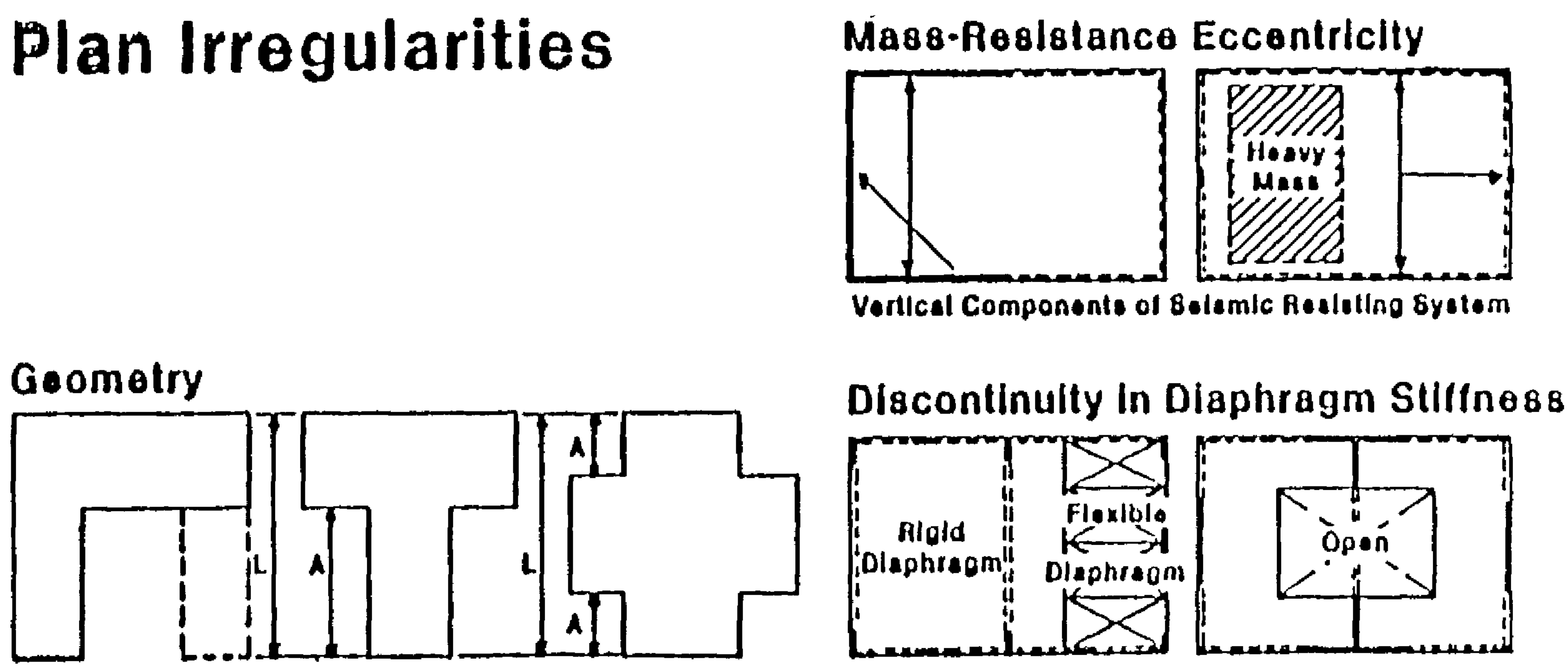


Details:
5. typical unbraced parapet and cornice
6. flat arch window openings
7. typical penetrated facade of residential buildings
8. large openings of ground floor shops

Wall systems:
9. bearing wall-- four to eight wythes of brick
10. typical long solid party wall
11. light/ventilation wells in residential bldg
12. non-structural wood stud partition walls

Figure 2-19c Unreinforced masonry bearing wall

Figure 13


Plan Irregularities
Geometry
L
A
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Mass-Resistance Eccentricity
Heavy Mass
Vertical Components of Seismic Resisting System
Discontinuity In Diaphragm Stiffness
Rigid Diaphragm
Flexible Diaphragm
Open

Figure 14

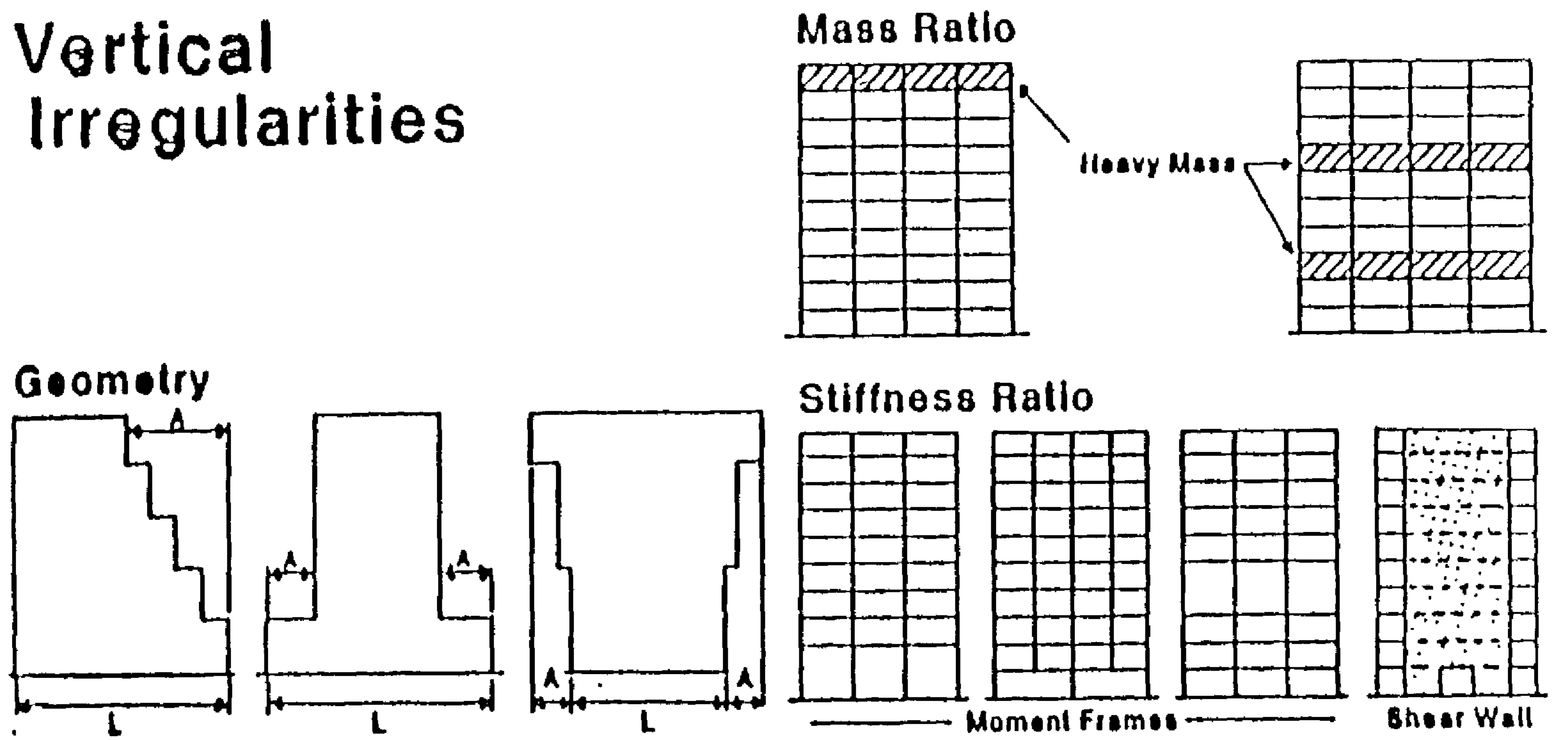

Figure 15

From SEAOSC Seminar, 1989