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METHODOLOGY FOR MITIGATION OF SEISMIC HAZARDS IN EXISTING UNREINFORCED MASONRY BUILDINGS:

CATEGORIZATION OF BUILDINGS

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Results are presented of a survey undertaken to provide basic data on the existing inventory of unreinforced masonry (URM) buildings in the United States. Buildings were categorized on the basis of characteristics of the design, material, or construction method that was perceived to be influential in the seismic response of that class of building. Investigative procedures are examined and survey findings are considered by region: New England; inland and coastal Carolina; New Madrid (Tennessee); Wasatch (Utah); Puget Sound; coastal California; and central Nevada. Information sources used in the field survey were found to be adequate for this generalized categorization study. Ways to improve the field procedures are suggested and recommendations for future efforts to develop a methodology for mitigation of seismic hazards in existing URM buildings are made.

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FOREWORD

This topical report is one of several reports prepared by ABK, A Joint Venture, for the National Science Foundation under Contract No. NSF-C-PFR78-19200. The overall objective of the contract is to derive a methodology for the mitigation of seismic hazards in existing unreinforced masonry buildings. This research supports the objective of the Disaster and Natural Hazard Research being conducted under the Applied Science and Research Applications program of the National Science Foundation.

The Joint Venture ABK consists of three firms, Agbabian Associates (AA), S.B. Barnes & Associates (SBB&A), and Kariotis & Associates (K&A), all in the Los Angeles area. The principal investigators for the three firms are R.D. Ewing for AA, A.W. Johnson for SBB&A, and J.C. Kariotis for K&A. The editor for the reports is J. Athey of AA.

This report presents the results and description of the investigative program conducted to provide basic data on the existing inventory of unreinforced masonry (URM) buildings in the United States. It includes a discussion of the investigative procedures, the data obtained from the program, and a categorization of the data. The objective of categorization was to recognize and identify commonalities of subgroups of URM buildings, so that meaningful analysis methods and tests could be designed to support the hazard mitigation research for existing URM buildings. Commonality of a subgroup is defined as common characteristics that affect structural response when a building is shaken by an earthquake. The results of the categorization and a description of the URM building subgroups selected for further study are included in this report. The principal contributor to this report is J.C. Kariotis from K&A.

Dr. J.B. Scalzi served as Technical Director of this project for the National Science Foundation and maintained scientific and technical liaison with the joint venture throughout all phases of the research program. His contributions and support are greatly appreciated.

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EXECUTIVE SUMMARY

This report describes a survey conducted to obtain information for the categorization of existing unreinforced masonry (URM) buildings in the United States. This categorization study is one of several tasks in an overall research program, sponsored by the National Science Foundation, whose objective is to develop a methodology for mitigation of seismic hazards in existing URM buildings.

The categorization study was conducted to support several aspects of the overall hazard mitigation program. The specific objectives of this study are (1) to identify the sizes, shape factors, materials, and construction methods utilized in horizontal elements; (2) to assist in the planning of a static and dynamic test program for typical horizontal elements (ABK, 1981b); (3) to identify the sizes, height-to-thickness ratios, materials, and construction methods utilized in URM walls; (4) to assist in the planning of a dynamic test program for typical URM walls subjected to out-of-plane motions (ABK, 1981c); (5) to aid in the planning of a static test program for the evaluation of typical interconnections in URM buildings (ABK, 1982a); (6) to assist in the planning of test procedures to determine the strength of typical URM; (7) to identify typical URM building characteristics that could be used to relate observed earthquake damage in URM buildings; (8) to assist in the development of analytical models and procedures for the verification of URM building performance in past earthquakes and the prediction of the probable performance of typical URM buildings when they are shaken by earthquakes; (9) to identify typical URM building elements that contribute to structural response modification, and incorporate these contributions into the final methodology (ABK, 1982b); and (10) to select representative URM buildings for analysis by the final methodology (ABK, 1982b) and use these analyses in the utilization phase.

The URM buildings were categorized using identifiers, where identifiers are defined as characteristics of the design, material, or construction method that are perceived to be influential in the seismic response of this class of building. The five selected identifiers of URM buildings are:

1. Construction materials in the floors, roofs, and internal partitions that are combined or connected to the URM wall elements.
2. The size and shape of the structures and structural components.
3. The degree of uniformity of the URM wall distribution around and within the building perimeter.
4. The details of interconnection between the vertical (URM walls) and the horizontal (floors and roofs) elements.
5. The criteria, if any, used for lateral load design.

These identifiers established a basis for categorization and helped define building characteristics that are common among existing URM buildings in the United States.

Based on a seismicity study (ABK, 1981a), six regions of the United States were selected for the survey: New England, Carolina Inland and Coastal, New Madrid, Wasatch, Puget Sound, and California Coast and Central Nevada. These regions represent the full range of seismicity in the United States, with an Effective Peak Acceleration (EPA) from 0.1 g to 0.4 g. The cities that were surveyed within these regions were those with substantial numbers of URM buildings, a diversity of buildings, a large number of a specific class of buildings, and a historical district. In each city, several sources of information were used, including visual inspection and interviews with building officials, engineers, architects, construction material associations, and construction industry associations. Extensive photographic coverage was used to record the features of many of the buildings.

The descriptions of URM buildings are achieved in a final table based on occupancy or use categories (industrial buildings, apartments, etc.), wherein each type is characterized by the main identifiers noted previously and as presented in four separate tables in the text. These four tables are presented here, in order that their numbered items can then be called out in the final categorization table.

In the final categorization table, each major URM occupancy type is characterized by the items used in the prior four tables; the technique of the final table is to use the identifying numbers of the earlier tables. These descriptions do not imply that other construction types do not exist, rather that the majority of buildings fit these descriptions. When two identifying numbers are listed for an occupancy, this indicates that a large number of buildings having both characteristics were discovered in the survey.

From this categorization, buildings were selected for study and analysis by the methodology (ABK, 1982b). The selected structures include industrial, public, apartment, commercial, and office buildings, as well as a public school. Some of the selected structures are actual existing buildings and some are composites of existing buildings. The composite buildings are similar in size, materials, and other characteristics to many buildings indigenous to a seismic zone or common throughout the United States.

TABLE 1. COMMON URM BUILDING CONSTRUCTION MATERIALS

EXTERIOR WALLS	ROOF	FLOOR	INTERIOR PARTITIONING
1. Solid brick of multi-wythe construction	1. Wood sheathing on wood subframing	1. Multi-layer wood sheathing on wood subframing	1. Nil, or with no significant restraint to interstory displacement
2. Cavity wall construction. Separated wythes of different materials	2. Cast-in-place concrete framing	2. Cast-in-place concrete framing	2. URM walls extending full story height
3. Stone or terra-cotta facing on brick interior wythes	3. Steel decking on steel subframing	3. Concrete fills in steel decking on steel subframing	3. Wood or metal framed partitions with finish materials extending full story height
4. Through-wall units of clay or concrete			

TABLE 2. CATEGORIZATION OF COMMON SIZES OF URM BUILDINGS

Height given in number of stories	Plan dimensions in feet (m)
1. Single story	1. 40 x 100 ft (12 x 30 m)
2. Single story with very high story height. Towers and steeples attached.	2. 60 x 150 ft (18 x 46 m)
3. 2 to 4 stories	3. 100 x 300 ft (30 x 91 m)
4. 5 to 7 stories	4. Greater than 200 x 400 ft (61 x 122 m)
5. More than 7 stories	5. Irregular in plan with multiple wings off central core

TABLE 3. DESCRIPTOR FOR DISTRIBUTION OF URM WALLS IN BUILDINGS SURVEYED

1. URM walls at perimeter. Building plan rectangular to near square. Fenestration reasonably uniform at exterior.
2. As above and with interior URM walls on a reasonably uniform pattern.
3. URM walls at perimeter. Building plan rectangular with long dimension exceeding least dimension by more than two. Nearly full building width openings at street frontage (may be on two adjacent sides at street corner). Penetration of exterior walls non-uniform.
4. Distribution of URM walls in an irregular plan pattern at building perimeter. Distribution of URM walls within building perimeter in an irregular pattern.
5. Distribution of URM walls in irregular plan pattern. Additional URM walls enclosing adjacent different story height spaces in an irregular pattern.

TABLE 4. INTERCONNECTION OF ELEMENTS OF URM BUILDINGS

1. URM walls tied to floors and roofs, perpendicular to wall.
2. As above, and with interior partitioning interconnected to horizontal framing by finish materials.
3. Little continuity or ties between URM walls and horizontal framing, or interior partitioning and horizontal framing.

TABLE 5. SUMMARY OF CATEGORIZATION SURVEY

OCCUPANCY OR USE CATEGORY	TABLE 4-1 CONSTRUCTION MATERIALS				TABLE 4-2 SIZE		TABLE 4-3 DISTRIBUTION OF URM WALLS	TABLE 4-4 INTERCONNECTION OF PARTS
	URM WALLS	ROOF	FLOORS	INTERIOR PARTITIONS	HEIGHT	PLAN SIZE		
Industrial buildings	1	1	1,2	1,2	3,4	3,4	2,1	1,2
Public schools	1,3,2	1	1,2	3,2	3	2,5	1,4	1,3
Public buildings	3,1	1	2,1	2,3	3	3,5	4	2
Apartments/hotels	1,2,3[a]	1	1	3[c]	3,4	1,2	1	2
	1,2,3[a]	1	2	3[c]	5	5,2	4[b]	2[c]
Commercial/office buildings	1,3[a]	1	1	3[c]	3	1,2	3	2[c]
		1	1	3[c]	4	2	3	2[c]
			2	3[c]	5	2,5	3,4[b]	2[c]
Churches	3,1	1		1	2	5	5	3
Post-1950 industrial	2,4	3,1		1	1	3,4	1	3
Post-1950 commercial	2,4	3,1	3,1	1	1,3	2,3	3	3

a. At street front
b. With interior courts for light and ventilation above first floor
c. In stories above first floor

SECTION 1

OBJECTIVES OF CATEGORIZATION

1.1 INTRODUCTION

The categorization of existing unreinforced masonry (URM) buildings in the United States is one of several tasks in an overall research project directed toward seismic hazard mitigation in existing URM buildings. The survey was undertaken to determine both the uniqueness and generalities of these buildings, so that meaningful analysis methods and tests could be designed to support the hazard mitigation research program. With an understanding of the diversity of this class of building, commonality of building subgroups can be recognized and categorized. This categorization will assist in making the development of a hazard mitigation methodology, that is national in scope, a manageable task.

The results of the categorization survey of URM buildings were used to plan the following segments of the research project:

- Determine masonry strength test procedures for all classes of masonry.
- Relate observed earthquake damage to identified subgroups of buildings.
- Identify size, shape factors, construction materials, and techniques utilized for construction of horizontal elements. Plan a dynamic test program (ABK, 1981b) for undesigned materials in horizontal elements that will identify their structural response to all the selected earthquakes (ABK, 1981a).
- Identify URM walls in terms of common height-to-thickness ratios, use of masonry materials, bonding of masonry units, and construction methods. Plan a dynamic test program to identify bounds of stability of cracked unreinforced masonry wall systems subjected to out-of-plane motions (ABK, 1981c).
- Plan a test program to evaluate existing interconnections of parts of URM buildings (ABK, 1982a). Plan the development of retrofit of interconnections for earthquake hazard reduction, incorporating the common relationships of the existing construction in URM buildings.

- Plan the development of an analytical procedure to verify observed past performance and predict probable performance of common URM buildings when shaken by earthquakes. Identify common assemblages in URM buildings to assist in the development of complete analytical models.
- Plan for identification and incorporation into the methodology (ABK, 1982b) of common elements of URM buildings that may modify structural response.
- Develop families of representative URM buildings for analysis by the methodology (ABK, 1982b).
- Plan a presentation of the analysis made of categorized URM buildings for incorporation in the utilization phase.

URM buildings will be categorized by identifiers that influence the seismic response of the structure. Here, we define "identifiers" as characteristics of the design, material, or construction method which assist in the categorization of the buildings. The geographic areas selected for the survey included all seismic zones, ranging from the lowest seismic zone to the highest (ABK, 1981a). Each geographic area was examined to find a commonality of identifiers, if it exists, or a uniqueness of construction that may be applicable to the time of construction or a regional custom.

The first section of this report presents the use of "identifiers" as a method for categorization and, in order to develop the important characteristics of buildings selected for the study, gives the parameters that will be crucial for the future efforts of the entire project. Section 2 describes the procedures used to survey existing URM buildings across the nation. Results of the field survey of URM buildings are grouped according to six geographic regions: New England, Carolina, New Madrid (St. Louis to Memphis), Wasatch (Utah), Puget Sound, and California Coast and Central Nevada. These findings are presented in Section 3. Section 4 categorizes URM structures according to the five identifiers itemized in Section 1. In Section 4 these discussions are condensed into respective tables so that a useful final table summarizes the categorization survey. Section 5 provides the final selection of URM structures to be analyzed for the seismic hazard mitigation study.

1.2 IDENTIFIERS FOR CATEGORIZATION

The criterion for selection of an identifier was its anticipated influence on the seismic response of the building, or its relationship to observed seismic damage as determined in a separate task that examined the performance of URM buildings subjected to earthquakes. Five general identifiers of URM buildings that were selected are:

- Construction materials in floors, roofs, and internal partitioning that are combined with the URM wall elements.
- Size of the structure and structural components (height and plan dimensions).
- Uniformity of distribution of URM walls around the building perimeter and within the building.
- Details of interconnection between vertical elements (URM walls) and horizontal elements (floors and roofs).
- Criteria used for lateral load design, or the absence of a lateral load design.

These identifiers are briefly discussed in the following paragraphs.

The construction material identifiers that are related to seismic response were the construction materials used in the floors and roofs. Floors and roofs fabricated of wood elements such as joists and boards or plywood have a structural response in the horizontal plane that can be generally characterized as attenuating high frequency ground accelerations but commonly amplifying input velocities and displacements. Floors and roofs fabricated with concrete or similar construction tend to act as rigid bodies that track with ground motions imparted to the edges of the horizontal element by the in-plane URM end walls. These bounds of performance are modified by the size, plan dimensions, and shape of the horizontal element, but a gradation of response from that of a rigid body through amplified elastic response to energy absorption by inelastic behavior can be predicted.

The size of a building when described as a height-to-length ratio of its URM external and interior walls is a parameter for in-plane response to ground motions. Story height influences the out-of-plane response of URM walls. Span-to-depth ratios for floor and roof diaphragms are a parameter for modifying the coupled mass response and out-of-plane wall response. The performance of any floor or roof diaphragm is also related to its construction materials.

The uniformity of the distribution of URM walls around the building perimeter influences the symmetry of response of building mass above grade. Non-uniformity of wall distribution around the building perimeter is related to the percentage of openings through the wall as well as the total length of wall on any side of the building. The frequency of URM walls that subdivide the internal building space is a significant factor in determining the excitation by ground motions of all parts of the building above grade. Elements that interconnect floors and roofs with the ground, such as interior partitioning other than URM, are an important response identifier even though their contribution to response and interstory displacement control is difficult to quantify.

The details of interconnection of parts of the building have the most significant single influence on probability of occurrence of life-threatening damage in URM buildings that may be shaken by moderate to strong ground motions. A review of earthquake damage, undertaken as an associated study, indicates that separation of parts of the building is the major life-safety hazard in URM buildings near earthquake epicentral areas. The life-threatening hazard in the large adjacent zone of moderate ground shaking is almost totally caused by separation of parts of the buildings.

The criterion used for lateral load design is expected to be a significant factor that can influence the performance of structures subjected to earthquake loads. The interchangeability of a wind or a seismic lateral design has been generally accepted by the design profession, when the design forces are of the same magnitude. The adequacy of such an interchange will be examined in the development of the methodology for earthquake hazard mitigation. If the construction of the building predates general use of lateral design concepts, either wind or seismic, it is anticipated that the construction materials will be utilized and interconnected with consideration of gravity loads only. Observation of earthquake damage has indicated that these classes of constructions are prone to having significant damage when subjected to a moderate intensity of ground shaking. In areas of strong ground shaking, collapse of undesigned buildings has been observed as contrasted with the general survival of buildings designed for lateral loads. The magnitude of the lateral force used in the design procedure does not appear to be a significant factor that influences the degree of damage.

1.3 PROPOSED STUDY OF CATEGORIZED BUILDINGS

Buildings, representative of those surveyed and categorized, will be studied by the analysis guidelines of the developing methodology (ABK, 1982b). The methodology will be used to determine structural response, predict performance and damage, assess damage and the life-safety hazard potential of the damage, and recommend retrofits. Present-day cost comparisons of recommended retrofits and alternative hazard mitigation ordinances and guidelines will be made. Alternative ordinances assessed will include those adopted or proposed by the Cities of Los Angeles, San Diego, Santa Rosa, and Long Beach, California, and the Commonwealth of Massachusetts. Hazard reduction programs for historical districts such as Pioneer Square, Seattle, Washington, will also be evaluated.

This study will provide an examination of the usability of the methodology. This usability will be tested for efficiency of use, as measured in required analysis time by a design professional. In addition, the cost effectiveness of this simplified methodology will be compared to the effectiveness of more complex analyses in matching probable seismic performance. That is, if more complex analysis methods can reasonably predict that existing construction does not constitute a significant life-safety hazard, retrofit costs for the building or its element are reduced to zero, thereby offsetting some increase in analysis costs. It is anticipated that improvements in response prediction and damage prediction can be cost effective when measured against rehabilitation and retrofit costs.

The full range of the categorization identifiers will be used in selecting the buildings to be studied. The selected buildings may include composites of several structures and/or specific structures for which construction data are available. It is anticipated that the selected buildings will be representative of 80 to 90 percent of those URM buildings in the geographical areas surveyed.

If some of the selected buildings are typical of existing buildings in several or all seismic zones, they will be analyzed for the earthquake design intensity of all applicable seismic zones. Moreover, retrofit strategies suitable for lower intensity seismic zones will be tested for the same building in higher intensity zones. This phase of the study will provide an assessment of probable performance of buildings subjected to earthquakes that may exceed their design intensity levels. It also can provide cost data for selection of hazard mitigation strategies. The selection of strategies can consider the costs of implementation vs. risk to life implied by each strategy.

The analysis of the categorized buildings will provide data for studies of implementation of hazard mitigation programs. Identified structures common to any seismic zone can be classed as having a degree of hazard. Implementation programs may then be ordered to provide the maximum annual reduction in earthquake hazard when based on a uniform annual investment in a long term hazard mitigation program.

The study will determine the adaptability of the methodology to the broad range of structures surveyed across the United States. Complex structures, such as very irregular buildings, may have earthquake response that cannot be defined by the general methods that are suitable for a methodology national in scope. The study will develop a commentary on the useful scope of the methodology to determine a reliable assessment of life-safety. The commentary will include guidelines using easily recognizable criteria to provide a warning to a user of any limitations of this methodology.

1.4 CHARACTERISTICS OF BUILDINGS SELECTED FOR STUDY

Three of the identifiers used to categorize existing URM buildings are anticipated to be the major factors in defining the earthquake response of the structures in each seismic zone of interest. These identifiers are construction materials used in floors and roofs, building size, and the distribution of URM walls around and inside the building. The other two identifiers, interconnection of parts of the building and original lateral load design criteria, are expected to affect damageability. These last two identifiers are not necessarily common to any seismic or geographic zone.

The characteristics of the buildings selected for study in each category shall be those that represent the majority of the category. If the category has a wide range in the identifiers, the category will be represented by two structures that represent the reasonable bounds of the majority. If the variation is in construction materials only, similar structures including the different construction materials will be evaluated by the methodology.

SECTION 2

PROCEDURES FOR FIELD SURVEYS

2.1 INFORMATION SOURCES

Surveys of existing URM buildings were made in Phase I studies (KKA, 1978). These preliminary investigations indicated a commonality of URM construction prior to 1940 across the United States. This study combined a visual and photographic survey with interviews of building officials, engineers, architects, representatives of construction material associations, and construction industry associations. In the Phase II survey persons previously contacted were interviewed with an expanded interview outline and the diversity of contacts was increased, both in the scope of their interest and in their geographic distribution.

Building officials provided information as to past and present design criteria. Their official contacts with rehabilitation and conversion programs for URM buildings provided a valuable information source as to the quality of existing construction. In addition, they provided information on concealed elements that are unique to a geographic area. This information is generally discovered by such rehabilitation projects.

Engineers and architects in general practice provided a source for a general categorization of construction materials and techniques used in current buildings incorporating URM walls. Current design methods and details are best described by these professional sources. This survey included architects that specialize in historical restoration. This group has special knowledge of historical materials and techniques used in buildings predating the experience of currently practicing architects and engineers.

Representatives of construction materials associations gave references for additional interview sources, as well as giving quantity estimates of use of current masonry materials. Some masonry associations maintain records of historical masonry usage and of significant masonry structures that were included in the survey.

Members of construction industry associations specializing in masonry gave descriptions of construction practices within their experience range. These firsthand descriptions provide a basis for understanding many of the observed techniques used for URM construction, both historical and current.

2.2 SELECTION OF GEOGRAPHIC AREAS

Geographic areas throughout the United States were selected to encompass the full range of probable seismicity (ABK, 1981a). The range of seismicity varies from the lowest hazard seismic zone, an Effective Peak Acceleration (EPA) of 0.1 g, to the highest hazard zone, EPA of 0.4 g. These geographic areas are labeled as the following regions:

New England Region
South Carolina Region, Coastal and Inland
New Madrid Region, Mississippi River Basin
Wasatch Region, Utah
Puget Sound Region, State of Washington
California Coast and Central Nevada Region

Cities within these geographic areas with substantial quantities of existing URM buildings were selected for a field survey. The selection of a city was based on its diversity of URM buildings, or having a large number of a specific class of buildings, such as large mill buildings.

2.3 SPECIAL INTEREST AREAS

The presence of a historical district in a city within the selected geographic area was also of special interest. Redevelopment districts incorporating existing buildings in the plan or including extensive rehabilitation or conversion projects were of special interest. The cities of Seattle WA, Memphis TN, Salt Lake City UT, St. Louis MO, Charleston SC, Columbia SC, Boston MA, San Diego CA, and Santa Rosa CA have one or both of these elements.

The maintenance of a historical district and the rehabilitation or conversion of the existing URM buildings generate a substantial source of information about existing construction and rehabilitation techniques. In many cases, rehabilitation or restoration work in progress can be examined in the field survey.

Certain geographic regions, such as New England, had an industrial expansion in the late 19th century and the early 20th century. These mill buildings utilized URM in their construction and constitute the largest sample of the class of very large and substantial URM buildings. Public school buildings of URM in the Seattle WA region have been given special study for earthquake hazard mitigation and were accorded preference as a special class in this geographic zone in the field survey planning.

2.4 LIMITATIONS OF THE FIELD SURVEY

Several days were allocated for the field survey in each geographic region to photograph representative buildings in each category, interview information sources (Sect. 2.1), and develop additional sources of historical information on URM construction techniques. In some cases, Sanborn maps, which are intended for use in fire insurance ratings, were utilized to locate significant clusters of URM buildings within the surveyed cities.

This field survey indicated that the information sources and techniques were adequate for the intended purpose, to develop a categorization of URM buildings in existence throughout the United States. These sources and techniques, and this report, were not intended to develop a comprehensive report on the cities discussed in Section 3. Development of a comprehensive report for use in hazard mitigation planning was undertaken by the City of Los Angeles and required several man-years of physical surveying and categorizing. However, programs intended to develop preliminary findings can use the techniques and procedures outlined herein. If ranges of hazard mitigation costs are to be developed, the investigator should be aware that the accuracy of the costs is highly dependent on the accuracy of the inventory survey. The hazard reduction cost to be assigned to each building is also critical and deserves study of each significant category in depth by the techniques described in Section 1.3.

SECTION 3

FIELD SURVEY FINDINGS

3.1 NEW ENGLAND REGION

The urban areas surveyed were Boston, Lowell, and Lawrence MA; Hartford CT; and Providence RI. This geographic region has the largest inventory of URM buildings due to the extensive development of commercial and manufacturing districts dating from the early 1800's to recent time. The older buildings generally utilize wood roof and floor construction in conjunction with the URM walls. A high percentage of recently constructed URM buildings use wood framed floors and roofs.

This surveyed region also includes the largest number of large industrial buildings using URM (Fig. 3-1). These large industrial buildings have a high percentage of perforations in the exterior walls, but generally have fire walls subdividing the long dimension of rectangular buildings. The urban commercial zones have a high percentage of URM buildings three to six stories in height (Figs. 3-2, 3-3, and 3-4). These buildings are fully utilized in the downtown core of the city. Utilization of the ground floor only is more common in areas outside the city core. These commercial buildings are typical of those in the remainder of the United States. However, many historic buildings that utilize stone in conjunction with brickwork exist in the region (Figs. 3-5 and 3-6). Ornamentation and use of elaborate masonry details near the roof of the building is common in this geographic region (Fig. 3-7). Systematic bracing of parapets is uncommon. Anchorage of masonry to interior framing was dictated by general conformance to fire regulations.

Churches in this region are unique in that their size is commonly larger than in other regions. The plan and elevations are more complex and elaborate in stonework and masonry detailing. Towers, steeples, and similar modifications to a rectangular plan and a common height are almost universal for the churches (Fig. 3-8).

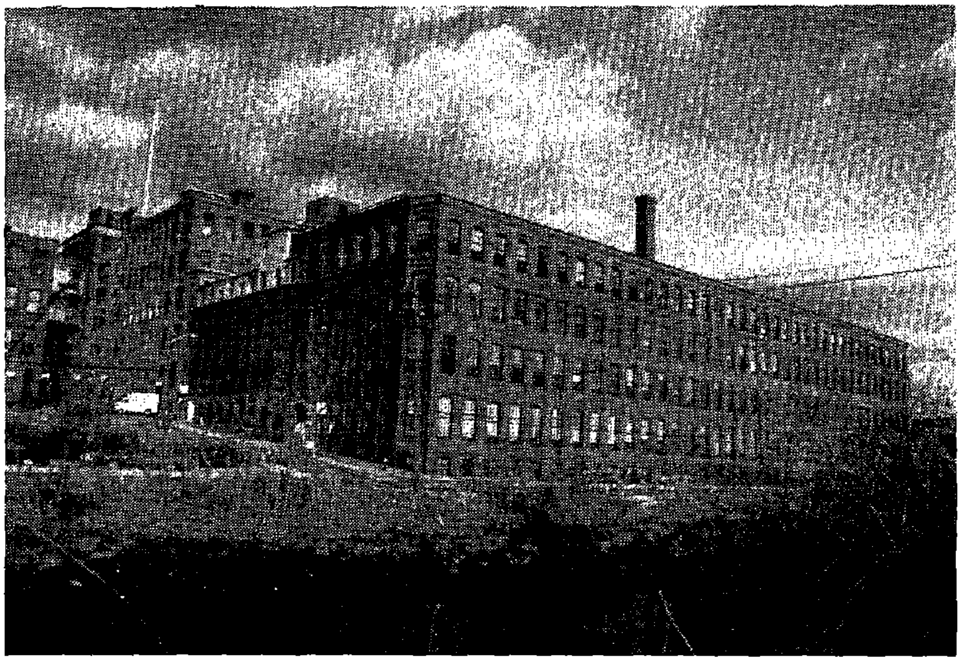

FIGURE 3-1. LARGE URM INDUSTRIAL BUILDING
NEW ENGLAND ZONE

FIGURE 3-2. URM COMMERCIAL BUILDING
NEW ENGLAND ZONE

FIGURE 3-3. URM COMMERCIAL BUILDING NEW ENGLAND ZONE

FIGURE 3-4. URM COMMERCIAL BUILDING NEW ENGLAND ZONE

FIGURE 3-5. URM BUILDING OF MASSIVE STONEWORK
NEW ENGLAND ZONE

FIGURE 3-6. URM BUILDING WITH STONE EXTERIOR
NEW ENGLAND ZONE

FIGURE 3-7. URM BUILDING, URM PROJECTIONS AT ROOF LEVEL

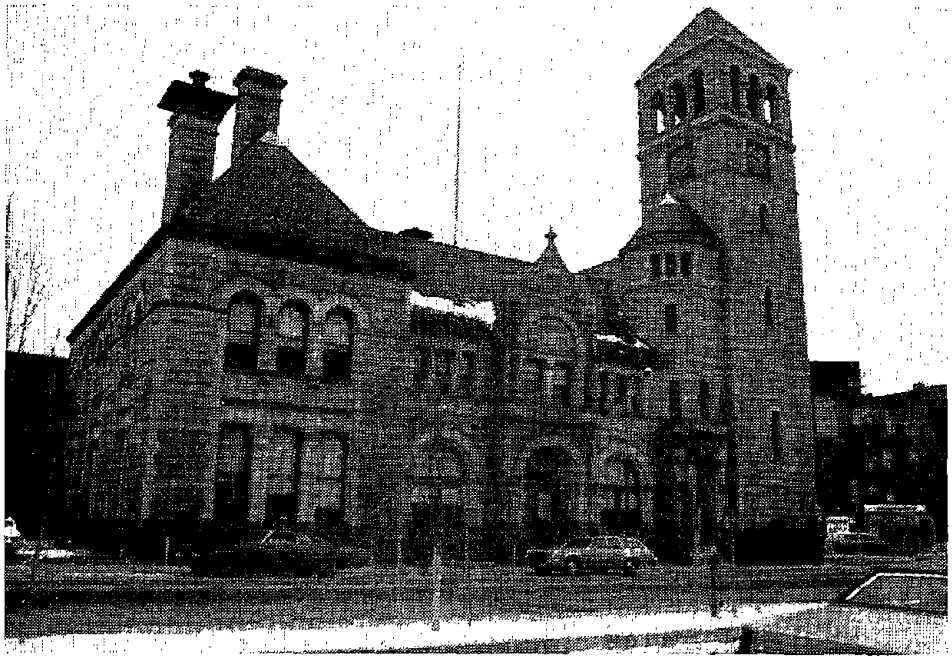

FIGURE 3-8. URM CHURCH WITH BELL TOWER NEW ENGLAND ZONE

The URM buildings in this region are generally well maintained and do not exhibit deterioration other than that due to age and use. The quality of masonry, except for some sandstones, is good. The mortar quality is good, and weathering, even in this adverse climate, does not appear to be a general problem.

3.2 CAROLINA INLAND AND COASTAL REGION

The urban areas surveyed were Columbia SC to represent the inland cities, and Charleston SC to represent the variety of historical structures in the old seacoast cities. Columbia has a large number of URM public buildings (Fig. 3-9), a typical commercial zone with URM buildings (Figs. 3-10 and 3-11), and a moderate amount of industrial URM buildings (Fig. 3-12). Charleston has special significance in that some buildings date from the 17th and 18th centuries and many predate the major earthquake of 1886 (Figs. 3-13 and 3-14). Preservation of these URM buildings within the historical city has been public policy. The city archives have records of descriptions and photographs of damage caused by the 1886 event. The repaired and reconstructed buildings can be examined to ascertain original construction and 1886 reconstruction. Many buildings that were undamaged by the 1886 event can also be examined.

The masonry materials of this region are common to both Columbia and Charleston except for the 17th century construction in Charleston. The bricks are softer than in the New England region and many pre-Civil War buildings used clay in lieu of lime mortar in the masonry walls (Figs. 3-15 and 3-16). These clay mortars were pointed on the exterior with lime mortar and can be commonly seen in the construction of the large residences. The soft bricks with clay or lime mortar are generally protected with a lime plaster. However, in some exposed churchyard walls, a lime mortar made from crushed sea shells has weathered without distress for up to 250 years.

The URM buildings in the coastal and inland region are representative of buildings of similar use throughout the United States. Mill and manufacturing buildings are comparable in size to those in the New

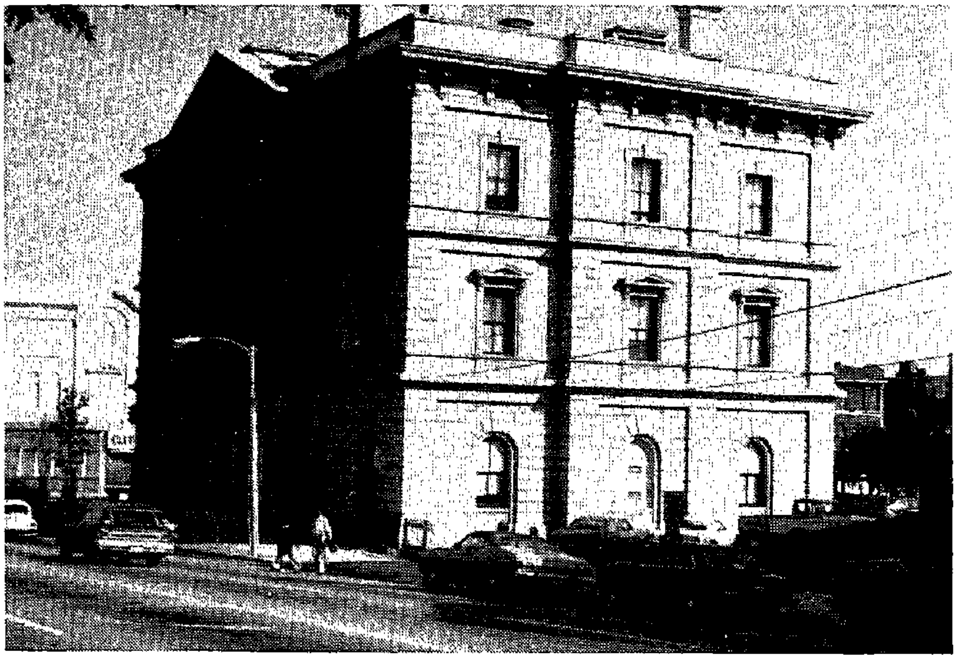

FIGURE 3-9. URM COURTHOUSE-SOUTH CAROLINA INLAND ZONE

FIGURE 3-10. URM COMMERCIAL BUILDING SOUTH CAROLINA INLAND ZONE

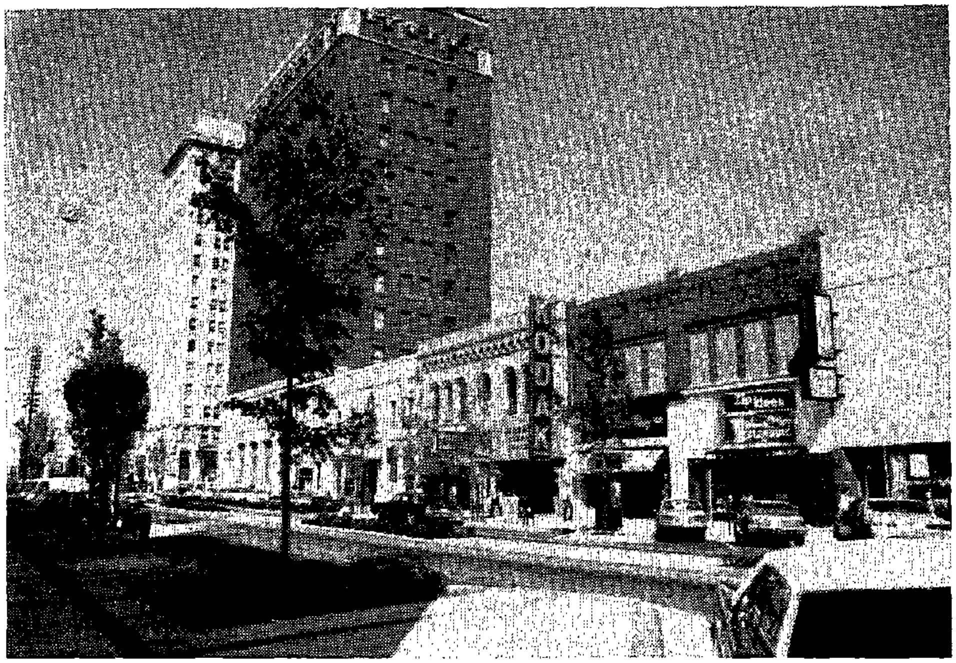

FIGURE 3-11. URM COMMERCIAL BUILDINGS
SOUTH CAROLINA INLAND ZONE

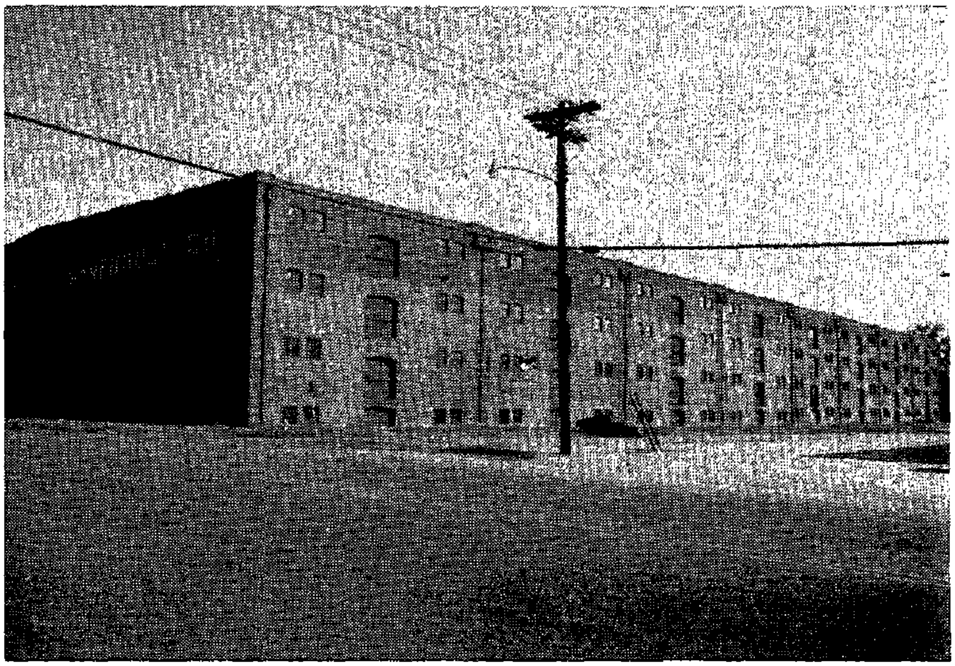

FIGURE 3-12. URM INDUSTRIAL BUILDINGS
SOUTH CAROLINA INLAND ZONE

FIGURE 3-13. URM COMMERCIAL BUILDINGS PREDATING 1886 EARTHQUAKE IN CHARLESTON, SC.

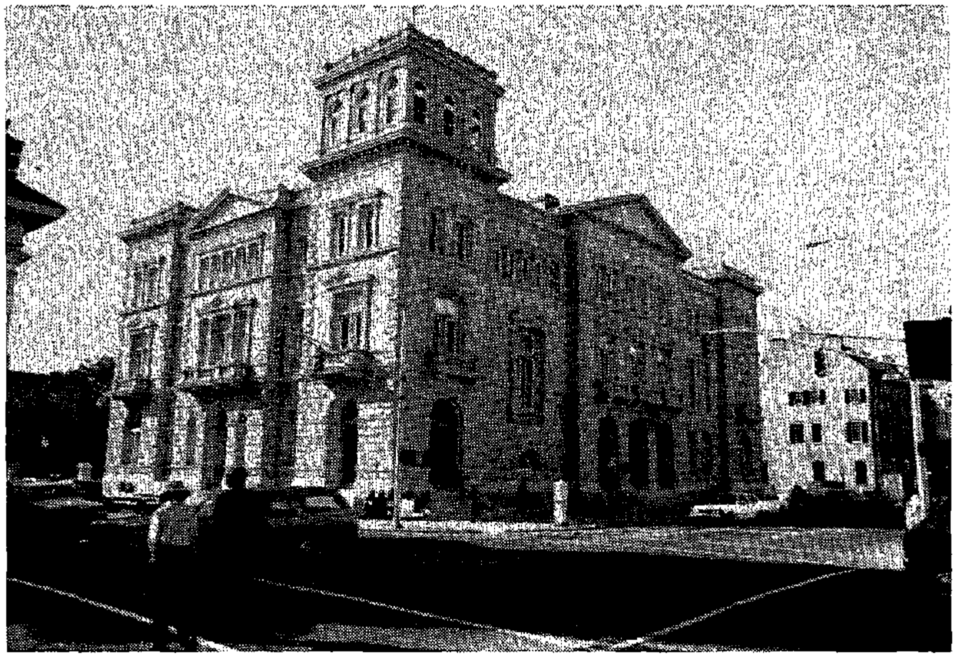

FIGURE 3-14. URM CHURCH PREDATING 1886 EARTHQUAKE IN CHARLESTON, SC.

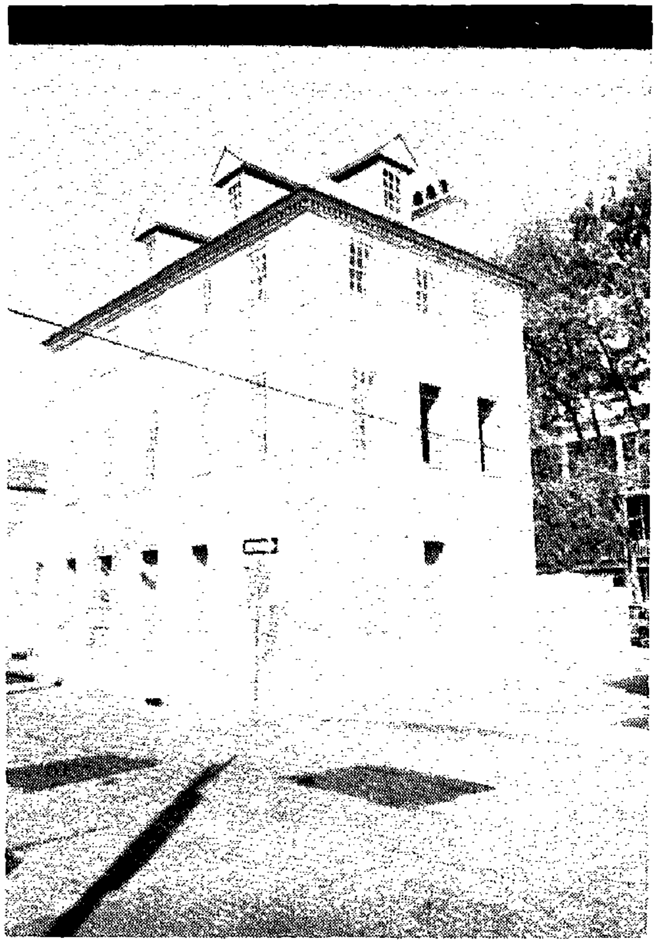

FIGURE 3-15. URM RESIDENCE CONSTRUCTED PRIOR TO 1886 WITH CLAY MORTAR

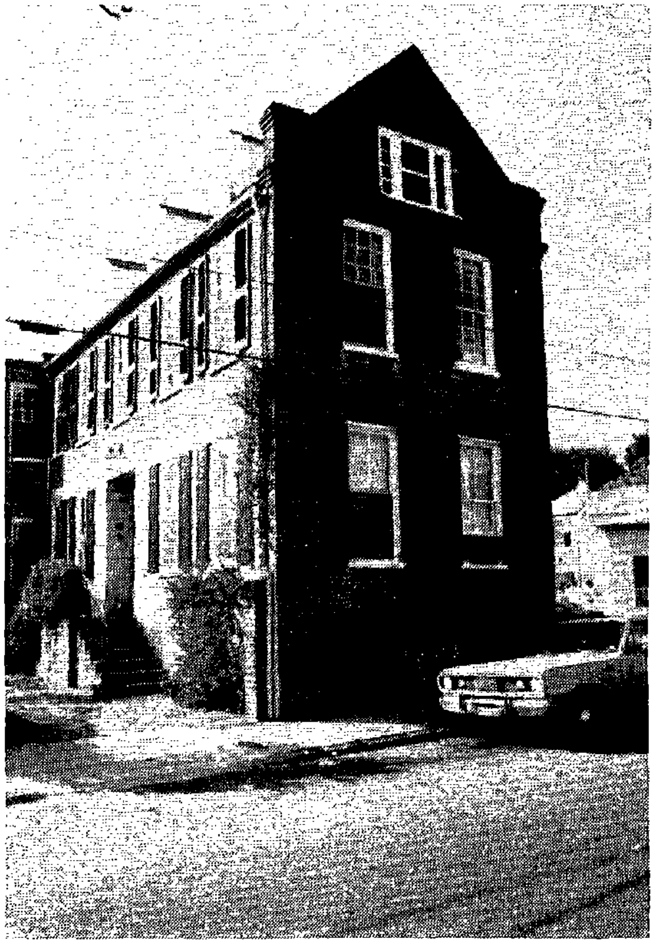

FIGURE 3-16. URM RESIDENCE CONSTRUCTED PRIOR TO 1886 WITH CLAY MORTAR

England region (Figs. 3-12 and 3-13), but are fewer in number. Commercial buildings generally have open fronts on the public way and generally do not exceed five stories in height (Figs. 3-10, 3-11, 3-13, 3-14, and 3-17). Wood floors and roofs are generally used in these URM buildings.

The existing URM buildings in the historical city of Charleston have had nearly continuous occupancy. Renovation and rehabilitation of Charleston's commercial and residential buildings has generally resulted in an increase in the number of occupants of these URM buildings (Fig. 3-18). Renovation and rehabilitation in the inland areas of Columbia is infrequent.

3.3 NEW MADRID REGION

Two cities with large commercial districts were surveyed in this region. Both cities have recently removed many URM buildings from the city core for redevelopment projects. Both cities now have reconstruction, conversion, and rehabilitation projects utilizing the remainder of their inventory of URM buildings.

The city of Memphis TN is within the higher seismic risk area of this seismic zone (EPA of 0.2 g). The present city center has many large commercial URM buildings incorporated in its city plan (Figs. 3-19 and 3-20). This and an adjacent industrial district include most of the URM buildings (Figs. 3-21 through 3-24). Suburban commercial centers and multiple residential structures comprise the remainder of the existing URM buildings. Current URM construction is generally used for small commercial structures or single-story industrial structures.

The quality of pre-1940 masonry is fair to good (Figs. 3-25 and 3-26). Hard-burned brick was available for exterior use and the lime mortar was generally of good quality. The larger commercial buildings using URM have internal framing of reinforced concrete or structural steel with concrete floors (Fig. 3-27). The pre-1940 industrial buildings may have woodframed (Fig. 3-28) or concrete floors. Post-1940 buildings

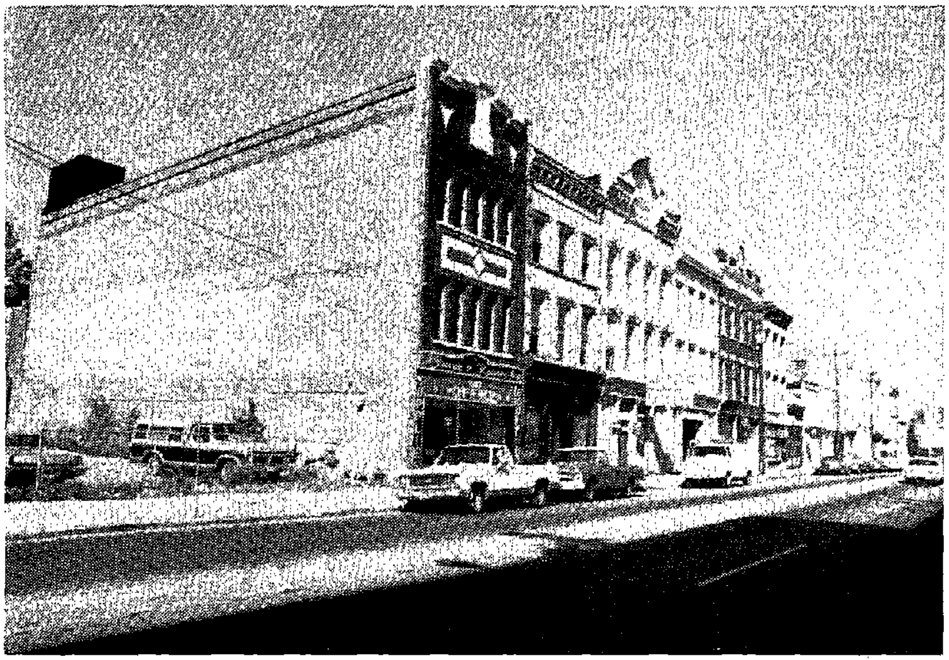

FIGURE 3-17. URM COMMERCIAL BUILDING,
POST-1886, CHARLESTON, SC.

FIGURE 3-18. OLD PUBLIC MARKET UTILIZED IN
HISTORIC DISTRICT, CHARLESTON, SC.

FIGURE 3-19. URM BUILDINGS,COMMERCIAL DISTRICT, MEMPHIS, TN.

FIGURE 3-20. URM BUILDINGS,COMMERCIAL DISTRICT, MEMPHIS, TN.

FIGURE 3-21. URM BUILDINGS, INDUSTRIAL
DISTRICT, MEMPHIS, TN.

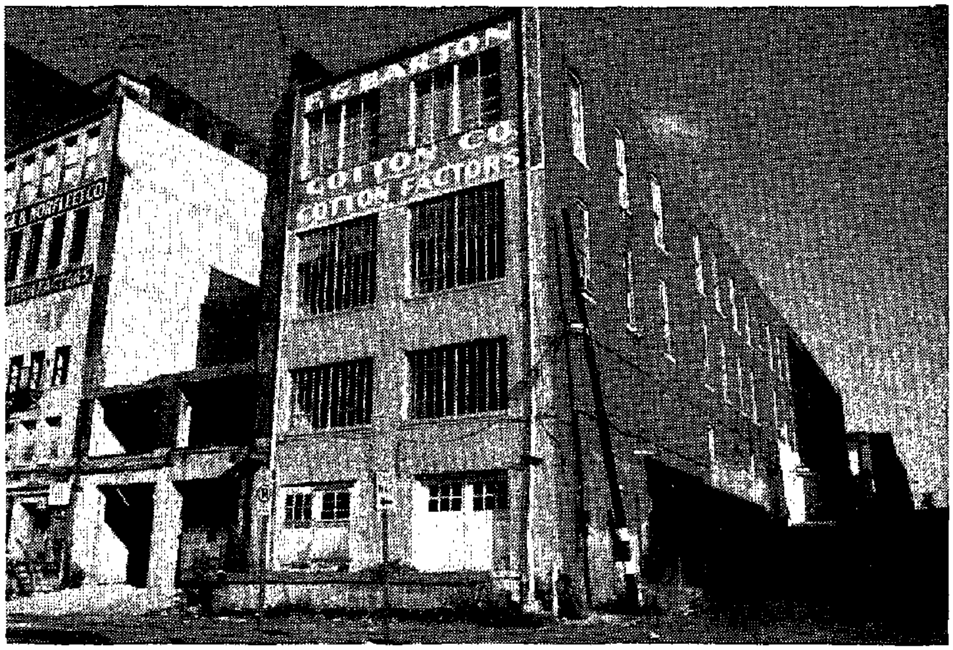

FIGURE 3-22. URM BUILDINGS, INDUSTRIAL
DISTRICT, MEMPHIS, TN.

FIGURE 3-23. URM BUILDINGS, INDUSTRIAL DISTRICT, MEMPHIS, TN.

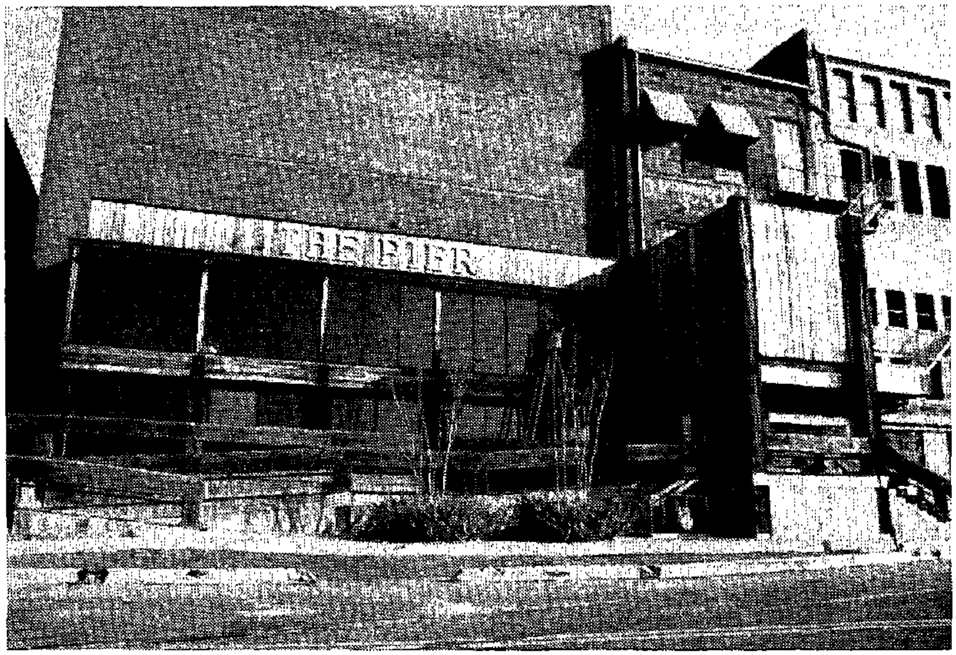

FIGURE 3-24. URM INDUSTRIAL BUILDING CONVERTED TO MULTIPLE HOUSING

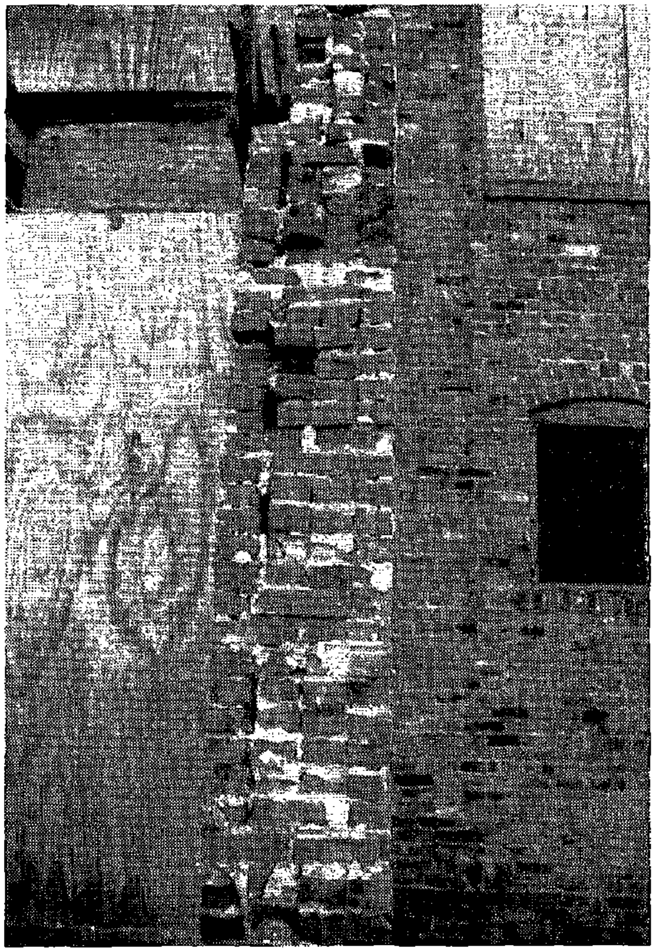

FIGURE 3-25. URM COMMERCIAL BUILDING
MEMPHIS, TN.

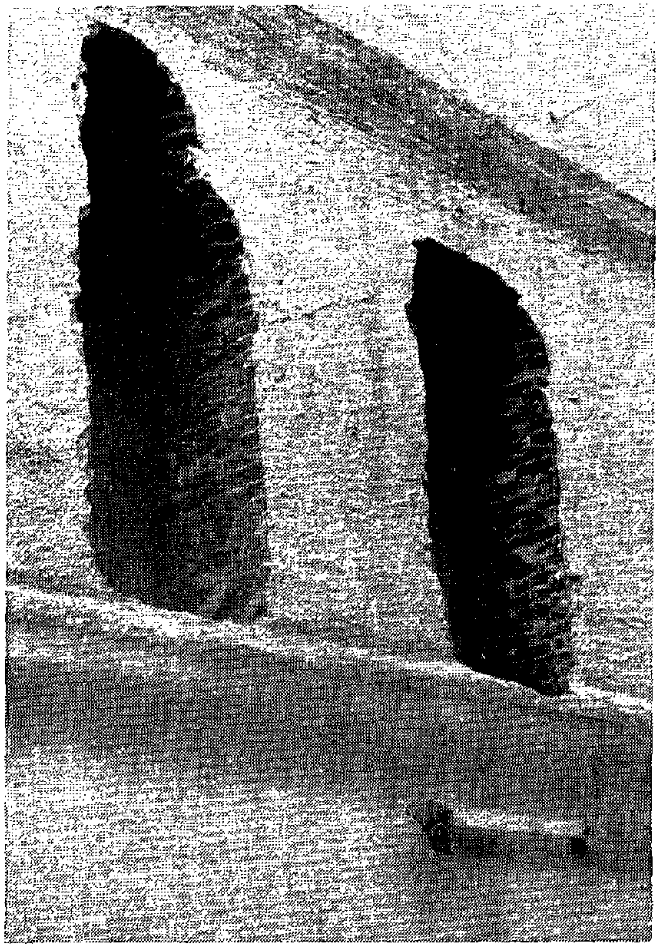

FIGURE 3-26. URM INDUSTRIAL BUILDING
MEMPHIS, TN.

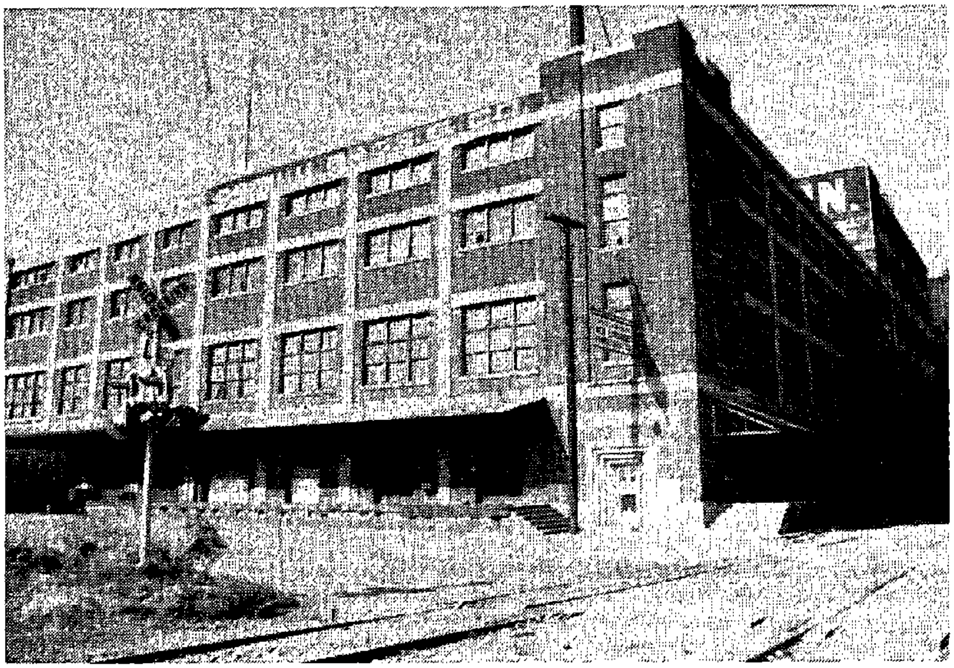

FIGURE 3-27. URM INDUSTRIAL BUILDING WITH INTERNAL CONCRETE FRAME

FIGURE 3-28. URM INDUSTRIAL BUILDING WITH WOOD FRAMED FLOORS

will generally use URM walls of concrete block rather than brick. Brick is generally used as nonstructural veneer in current construction.

The city of St. Louis with its suburbs probably represents the largest single city inventory of URM buildings in a significant seismic zone. The seismic risk zone (EPA of 0.1 g) is lesser than that of Memphis and is equal to the New England seismic zone. The development of the commercial and industrial district was more intensive (Fig. 3-29), and the commercial structures are taller than those in other geographic regions (Figs. 3-30 and 3-31). The industrial structures are equal in size to those in the New England region and in many cases higher (Figs. 3-32, 3-33, and 3-34). The URM buildings are concentrated in the city core, while the suburban area has structures that are comparable in size to other surveyed areas. Multi-family housing constructed prior to 1940 generally utilized URM walls.

Almost any structure in any other region, with the exception of historical buildings, will have its equivalent here. The quality of masonry in the St. Louis area is good to excellent (Fig. 3-35). The existing mortar is better than the average used throughout the United States. The older industrial buildings use wood floor and roof framing. The larger and more recent (post-1920) typically use concrete floor framing. The large commercial buildings have internal frames of structural steel and concrete (Fig. 3-36). Use of cast-iron fronts is common at the street front in the lowest level in older commercial buildings (Fig. 3-37). The St. Louis area also has multi-story cast-iron framing on the street fronts. The maximum height of traditional cast-iron framing discovered in this survey was in the St. Louis area (Fig. 3-38).

3.4 WASATCH REGION

The cities surveyed in this region were Ogden, Provo, and Salt Lake City UT. The urban core of Salt Lake City was selected as representative of the region.

The existing URM buildings are similar to those of the Puget Sound and California coast regions. The largest URM buildings are

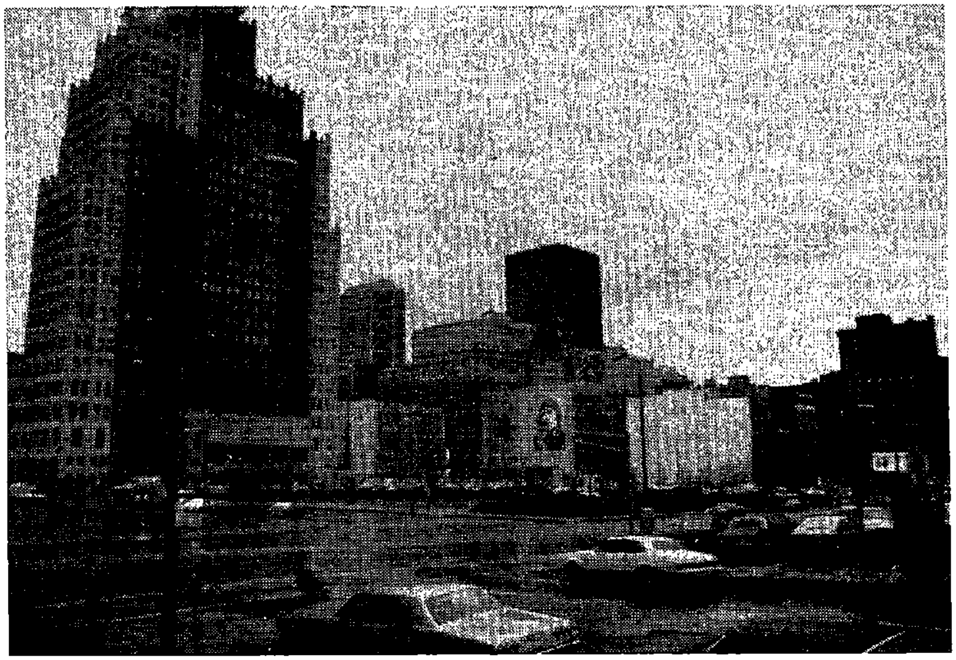

FIGURE 3-29. SKYLINE OF ST. LOUIS COMMERCIAL DISTRICT

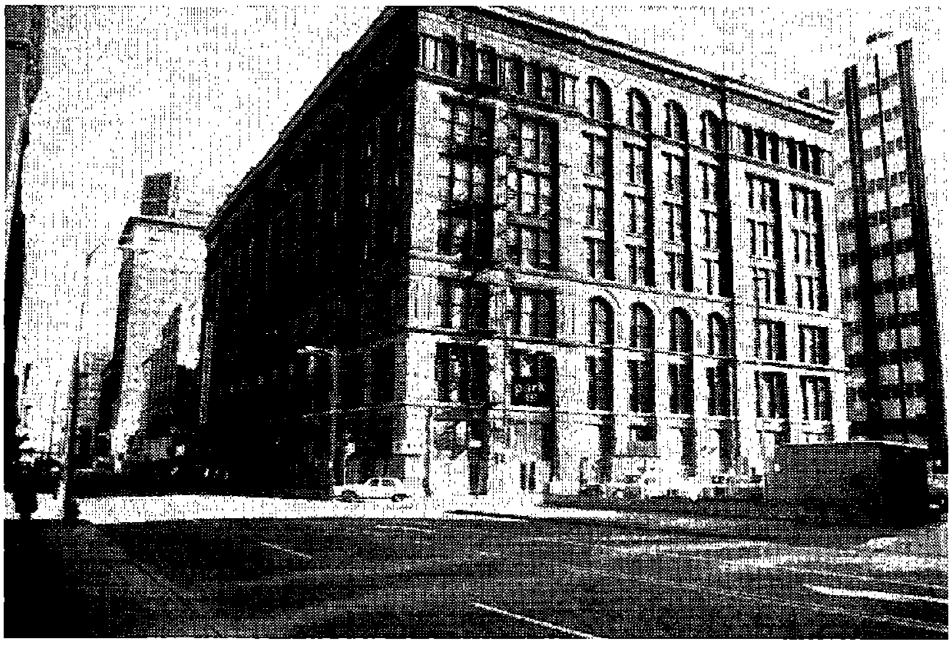

FIGURE 3-30. URM COMMERCIAL BUILDINGS, ST. LOUIS, MO.

FIGURE 3-31. URM COMMERCIAL BUILDINGS, ST. LOUIS, MO.

FIGURE 3-32. URM INDUSTRIAL BUILDINGS, ST. LOUIS, MO.

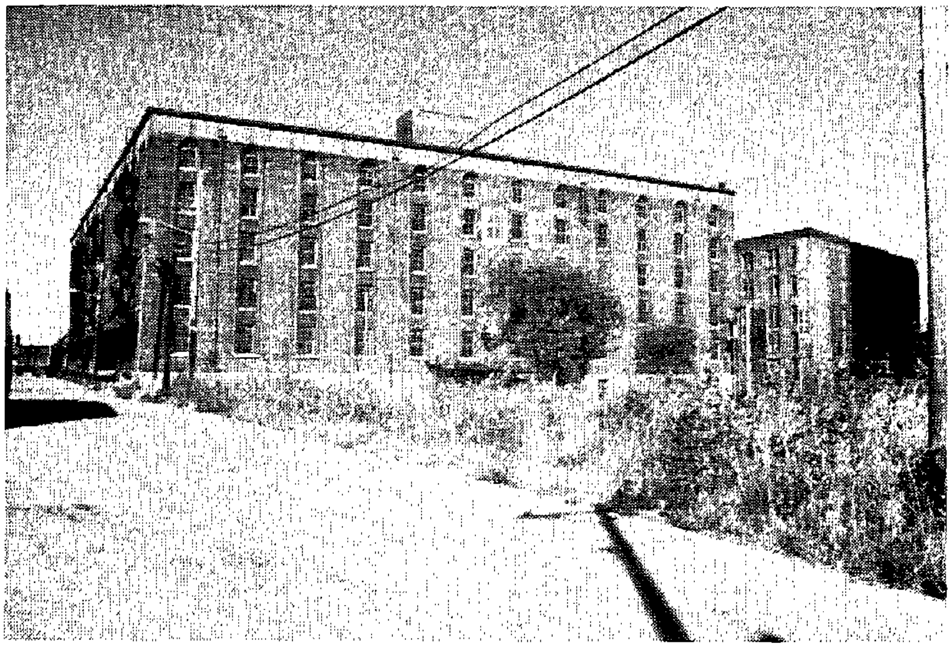

FIGURE 3-33. URM INDUSTRIAL BUILDINGS,
ST. LOUIS, MO.

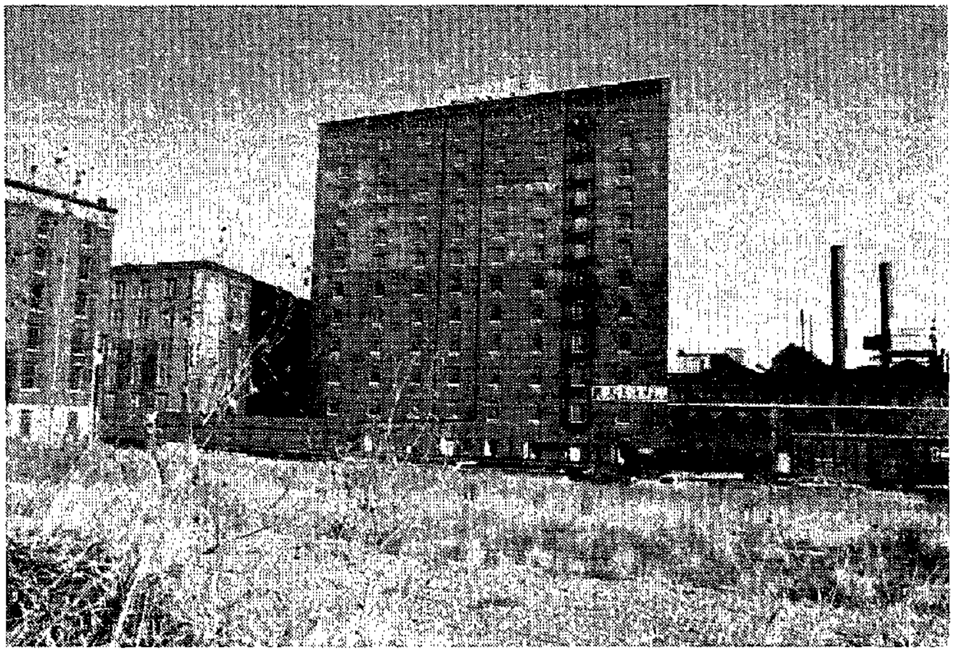

FIGURE 3-34. URM INDUSTRIAL BUILDINGS,
ST. LOUIS, MO.

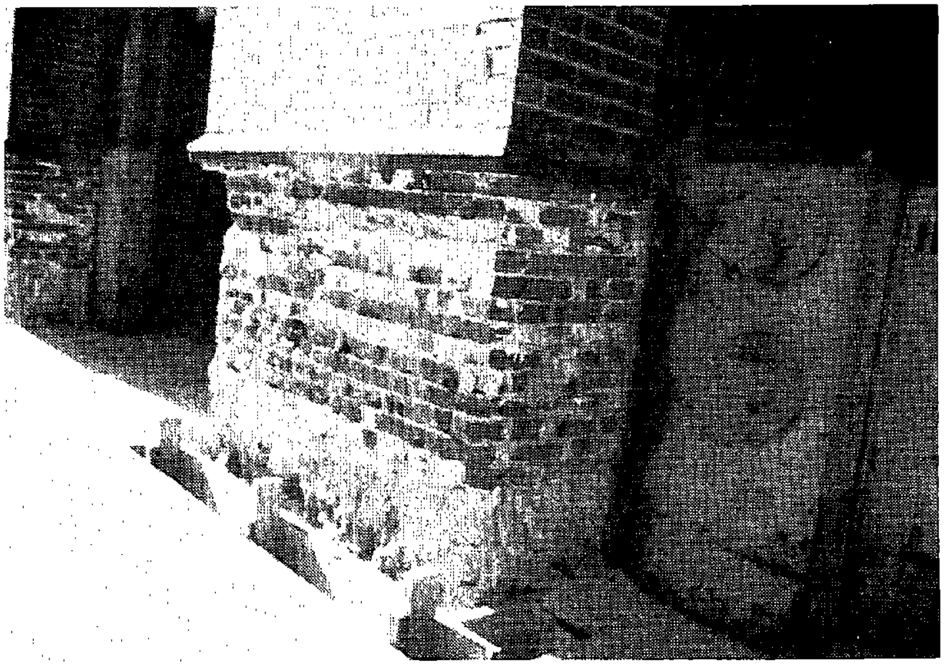

FIGURE 3-35. URM COMMERCIAL BUILDING
ST. LOUIS, MO.

FIGURE 3-36. URM COMMERCIAL BUILDING WITH INTERNAL
FRAME OF STRUCTURAL STEEL AND CONCRETE

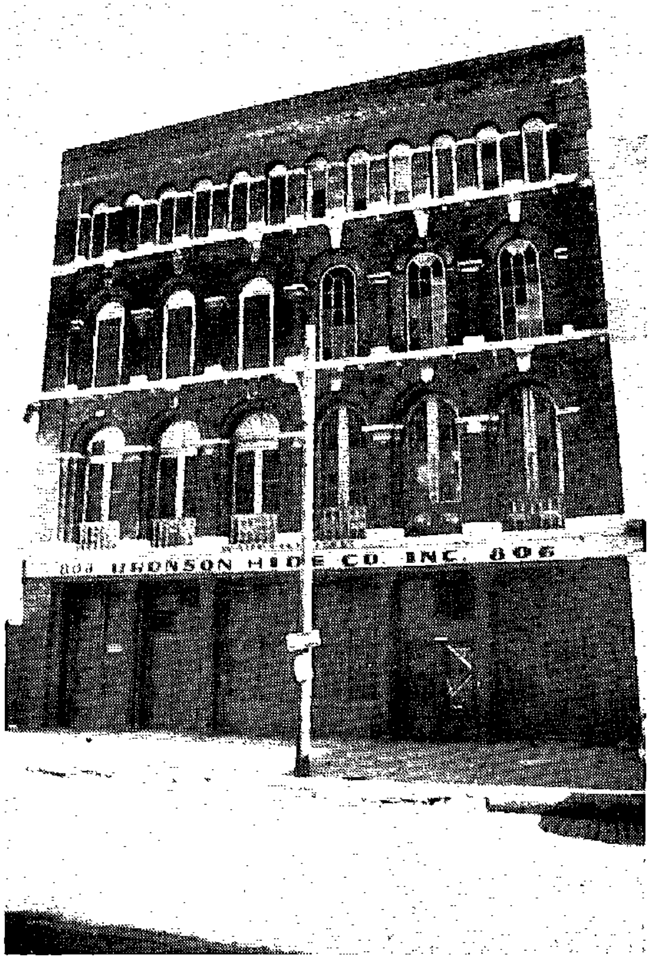

FIGURE 3-37. URM COMMERCIAL BUILDING WITH CAST-IRON FRAMING AT STREET LEVEL, ST. LOUIS, MO.

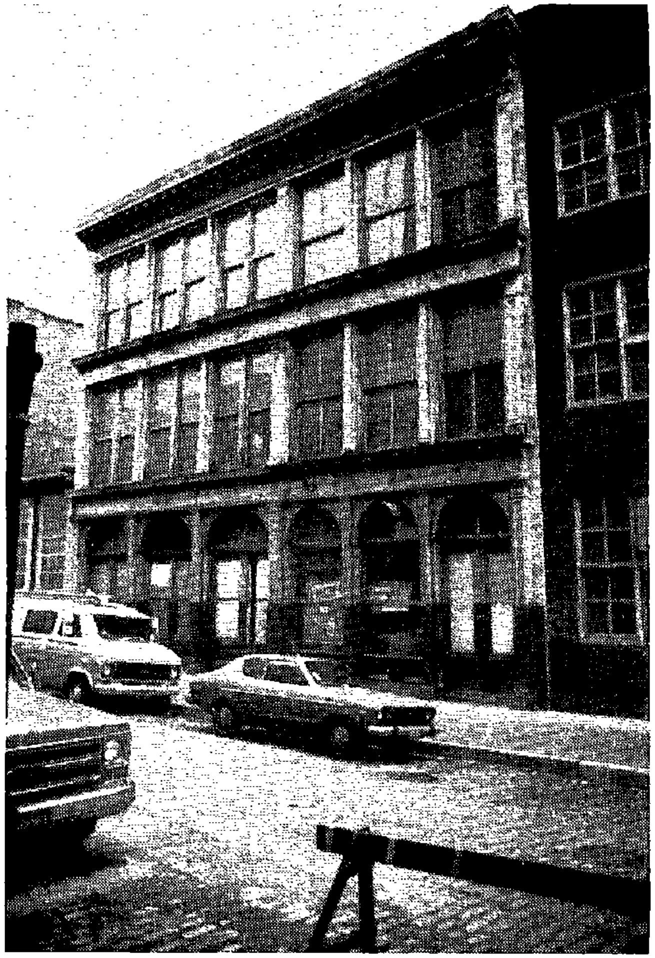

FIGURE 3-38. URM COMMERCIAL BUILDING WITH MULTI-STORY CAST IRON FRAMING ST. LOUIS, MO.

industrial buildings (Fig. 3-39), but are smaller than those industrial buildings in the eastern half of the United States. Commercial buildings of URM are utilized in the city center (Figs. 3-40 and 3-41). Renovation of existing commercial buildings is common (Figs. 3-42 through 3-45), and the URM buildings have a high degree of utilization. The commercial buildings are generally not as tall as those constructed in the eastern United States. The taller buildings, over four to five stories, will generally have interior framing of structural steel and concrete or of reinforced concrete alone (Fig. 3-46). But, of the gross floor area represented by the existing URM buildings, probably three-quarters of the total URM building area is represented by buildings that are framed in wood construction.

Preservation and restoration of buildings with historical qualities are common, and the interviews indicated that this trend will continue (Figs. 3-47 and 3-48). Strengthening for seismic forces by traditional methods has been undertaken for hospital facilities (Figs. 3-49 and 3-50). A public policy for seismic hazard reduction for private buildings has not been codified, and structural modifications of buildings converted to increased occupancy levels have been based on professional judgments by architects and engineers.

Multi-family housing adjacent to the central city commonly utilizes URM walls and wood-framed floors and roofs. The sizes of the apartments have the same range as those surveyed throughout the United States (Figs. 3-51 and 3-52). URM was used for older single-family residences (Fig. 3-53) in traditional designs.

Public school buildings constructed with URM walls are currently being utilized. Large areas of fenestration are common in these buildings (Fig. 3-54). These schools are in use only in the area immediately adjacent to the central city; however, post-1940 buildings do have URM in-filled walls (Fig. 3-55). Demolition of an existing school building in this area indicates that the URM has substantial tensile capacity (Fig. 3-56).

FIGURE 3-39. URM INDUSTRIAL BUILDING,
SALT LAKE CITY, UT.

FIGURE 3-40. URM COMMERCIAL BUILDINGS,
SALT LAKE CITY, UT.

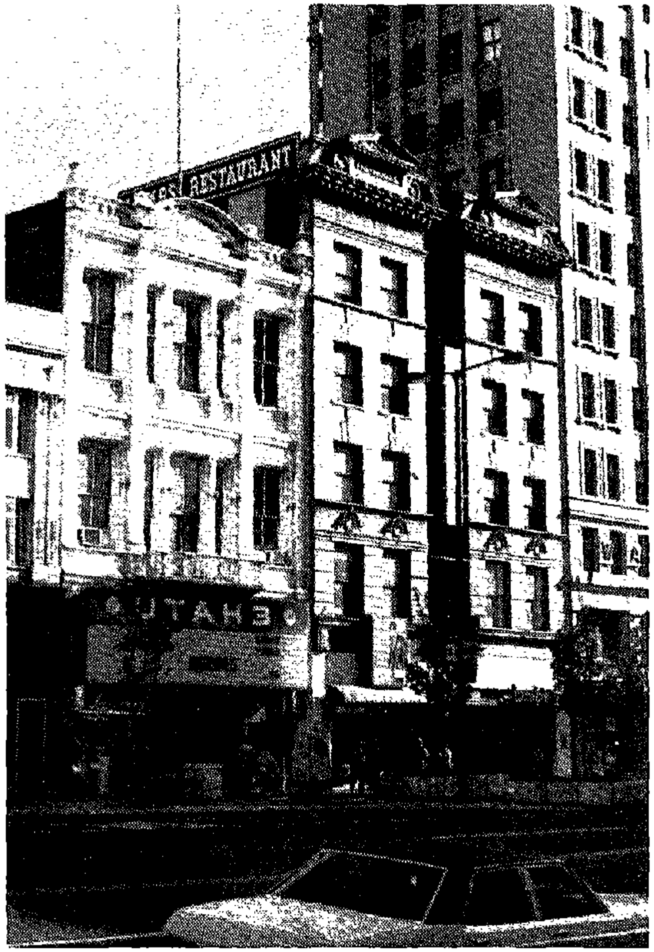

FIGURE 3-41. URM COMMERCIAL BUILDINGS,
SALT LAKE CITY, UT.

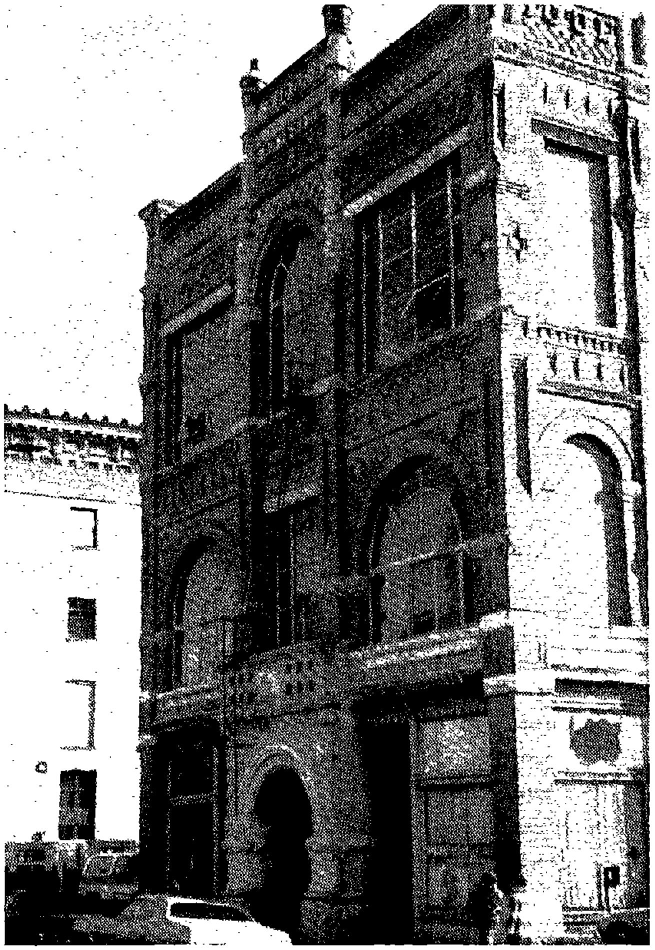

FIGURE 3-42. URM COMMERCIAL BUILDING
RENOVATED FOR CONTINUING USE

FIGURE 3-43. URM COMMERCIAL BUILDING RENOVATED FOR CONTINUING USE

FIGURE 3-44. URM COMMERCIAL AND MULTI-FAMILY HOUSING RENOVATED FOR CONTINUING USE

FIGURE 3-45. URM COMMERCIAL BUILDING RENOVATED FOR CONTINUING USE

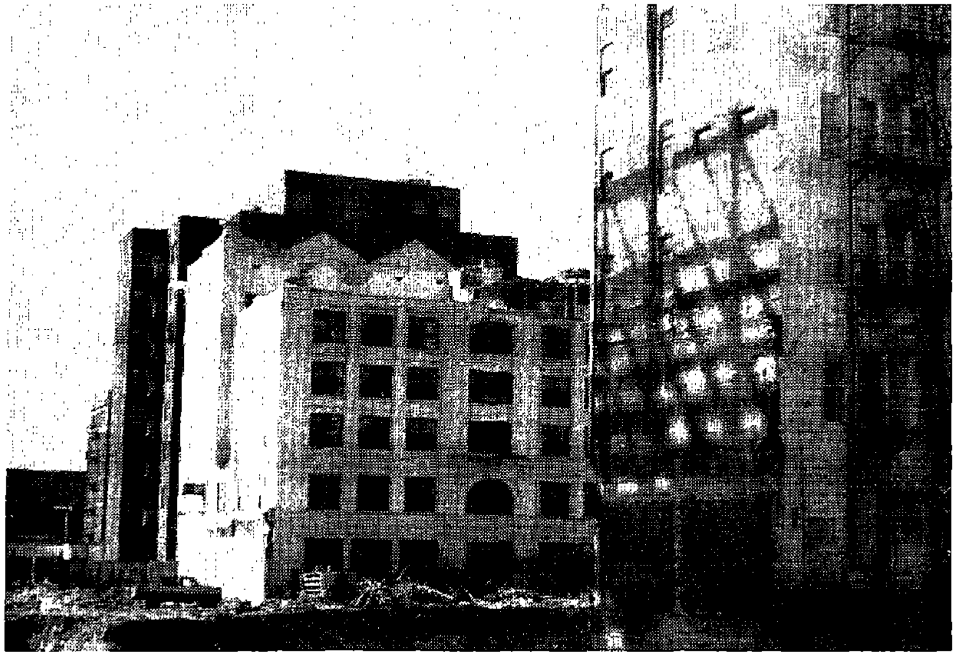

FIGURE 3-46. MULTI-STORY URM BUILDING WITH INTERIOR STRUCTURAL FRAMING OF REINFORCED CONCRETE AND STRUCTURAL STEEL

FIGURE 3-47. HISTORIC PRESERVATION OF URM THEATRE
SALT LAKE CITY, UT.

FIGURE 3-48. HISTORIC PRESERVATION OF URM THEATRE
SALT LAKE CITY, UT.

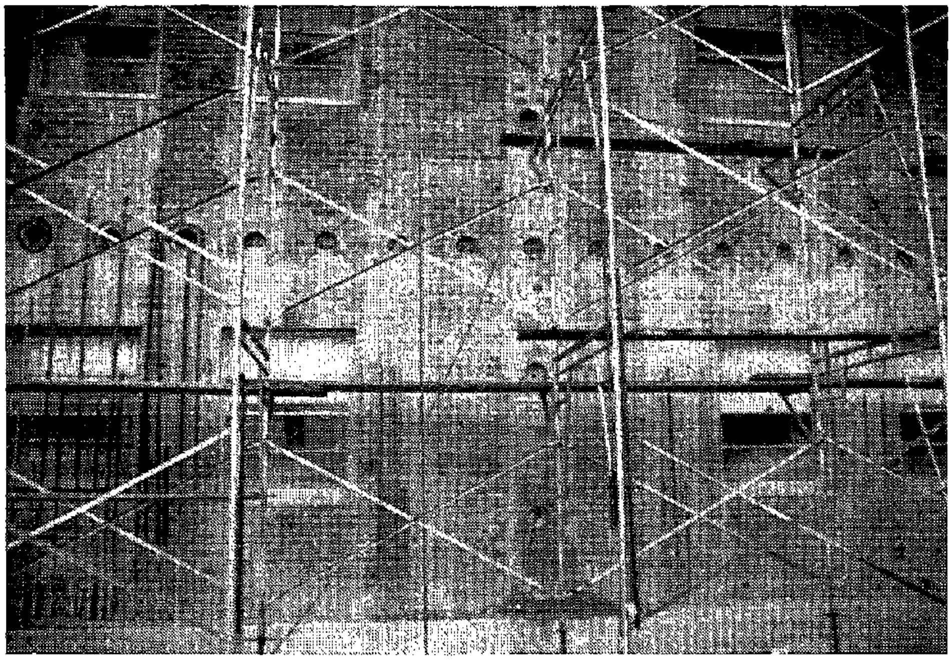

FIGURE 3-49. SEISMIC STRENGTHENING OF URM VA HOSPITAL BY ADDITION OF REINFORCED WYTHE OF MASONRY

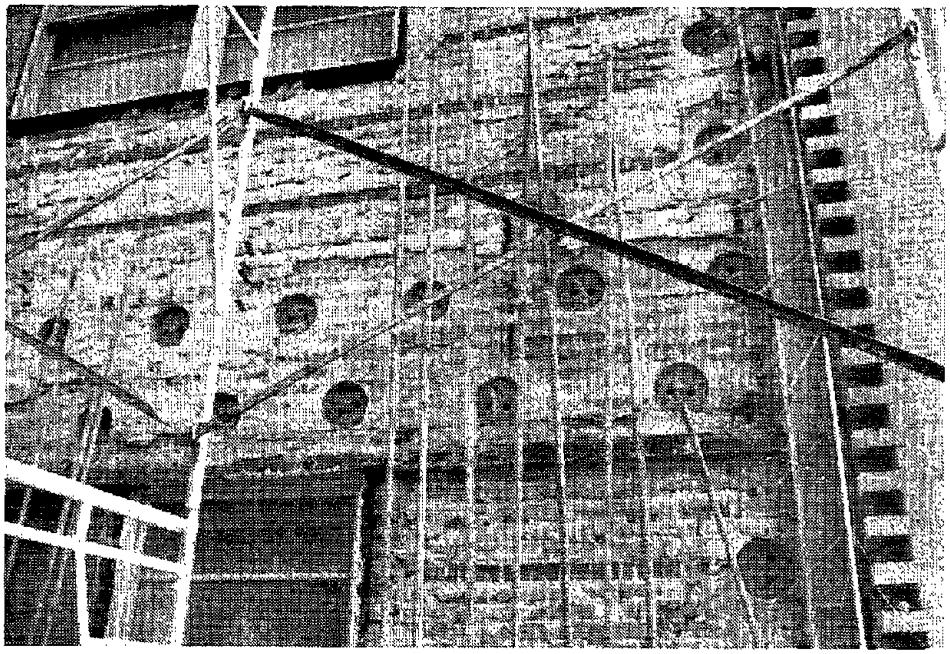

FIGURE 3-50. SEISMIC STRENGTHENING OF URM VA HOSPITAL BY REMOVAL OF BRICK WYTHE AND REPLACEMENT WITH REINFORCED WYTHE

FIGURE 3-51. URM MULTI-FAMILY HOUSING, SALT LAKE CITY, UT.

FIGURE 3-52. URM MULTI-FAMILY HOUSING, SALT LAKE CITY, UT.

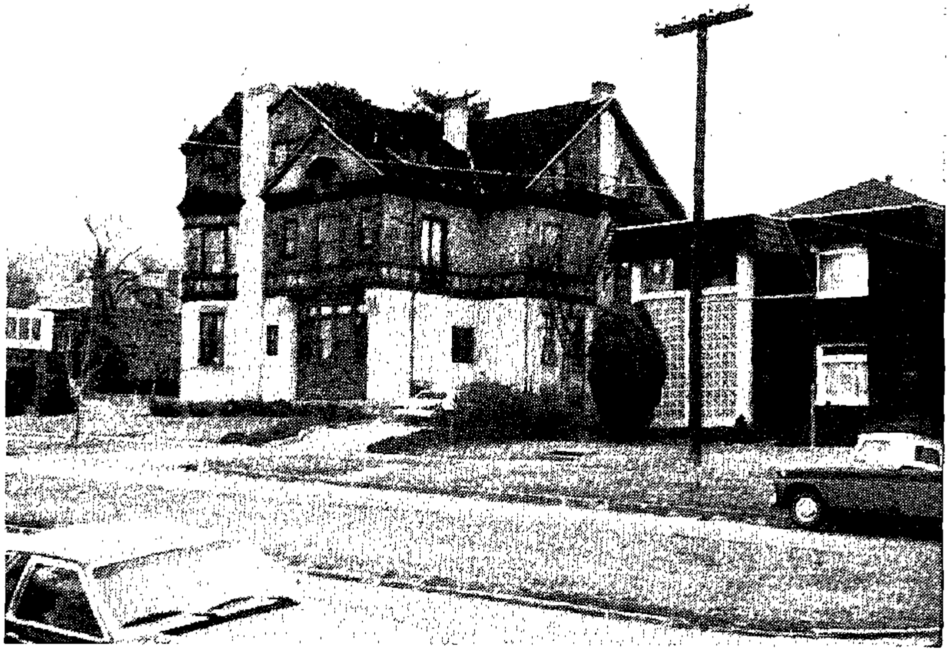

FIGURE 3-53. URM RESIDENCE,SALT LAKE CITY, UT.

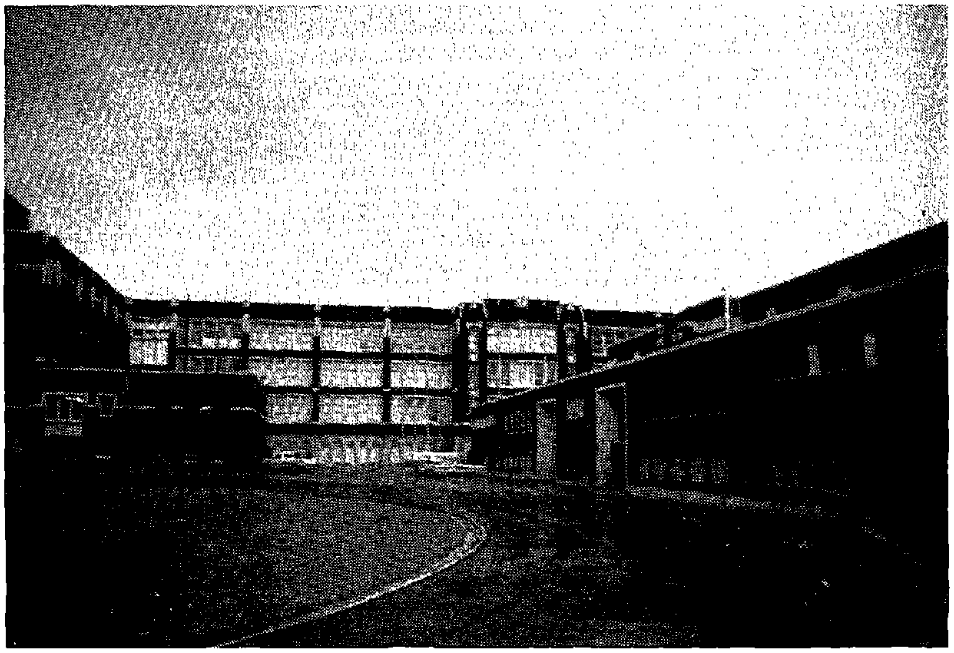

FIGURE 3-54. URM PUBLIC SCHOOL BUILDING,
SALT LAKE CITY, UT.

FIGURE 3-55. URM PUBLIC SCHOOL BUILDING,
SALT LAKE CITY, UT.

FIGURE 3-56. DEMOLITION OF URM SCHOOL
SALT LAKE CITY, UT.

The quality of masonry in this region is good to excellent (Figs. 3-57 and 3-58). Anchorage of wood framing to walls is equivalent to the observed nationwide practice. URM construction in the urban areas of Provo and Ogden is identical to that observed in the Salt Lake City area, except that the maximum height of commercial buildings is four to five stories.

3.5 PUGET SOUND REGION

The city of Seattle was chosen as the urban area representative of this region. The older section of the city was developed as a commercial and industrial district around the turn of the century (Fig. 3-59). Adjacent to the waterfront, blocks of the older buildings comprise an area undergoing rehabilitation and restoration (Fig. 3-60). The size of the downtown commercial buildings, both in plan and height, approaches the size of the large URM buildings of St. Louis MO. Six or more stories in height is common and the total width of the window openings is a large percentage of the walls' length (Fig. 3-61).

An occupancy of special significance in the Puget Sound region is the URM public schools. These schools have been shaken by two earthquakes recorded in Olympia, south of Seattle. These recorded motions were studied as design seismic input for the geographic region (ABK, 1981a). In addition, 22 URM buildings used by the Seattle Public Schools were surveyed by consulting engineers in 1977. The purpose of the survey was to perform a limited evaluation and, from this limited evaluation, to recommend elimination or reduction of specific high-risk hazards. Reported damage to these schools in the 1949 and 1965 earthquakes includes cracking, separation, or collapse of chimneys, gable ends, and cornices. Wall cracking and ceiling damage were also reported. Breakage of glazing was not reported.

These schools are large and have extensive fenestration in some walls (Fig. 3-62). Many are characterized by high-pitched roofs and large gable ends (Figs. 3-63 and 3-64). Through-wall anchors of the gable end to the roof framing are visible in Figure 3-63. These anchors were installed after separation was caused by a recent earthquake.

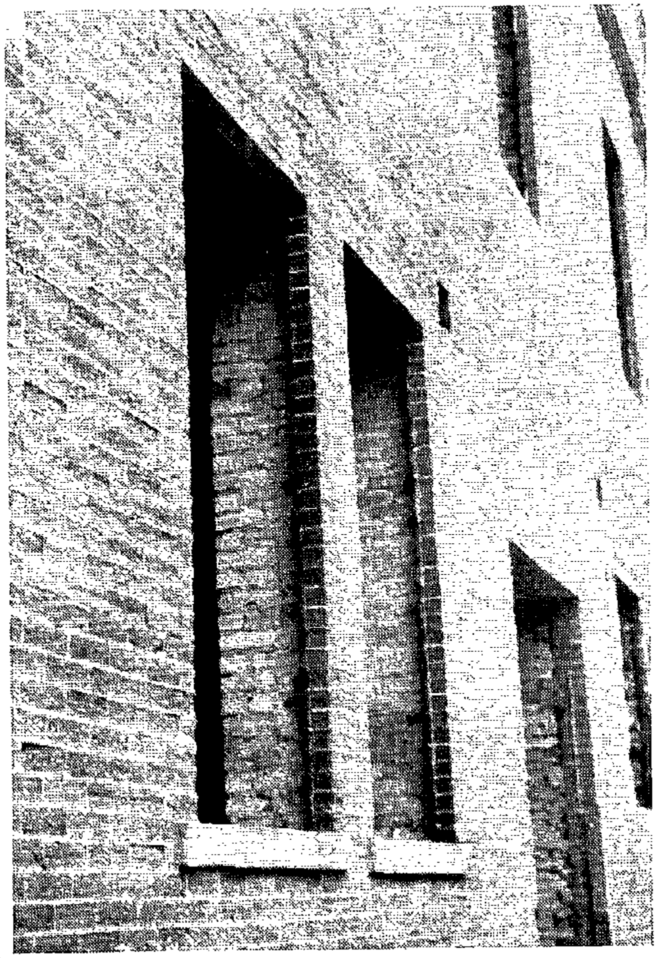

FIGURE 3-57. URM MASONRY, SALT LAKE CITY, UT.

FIGURE 3-58. URM MASONRY, SALT LAKE CITY

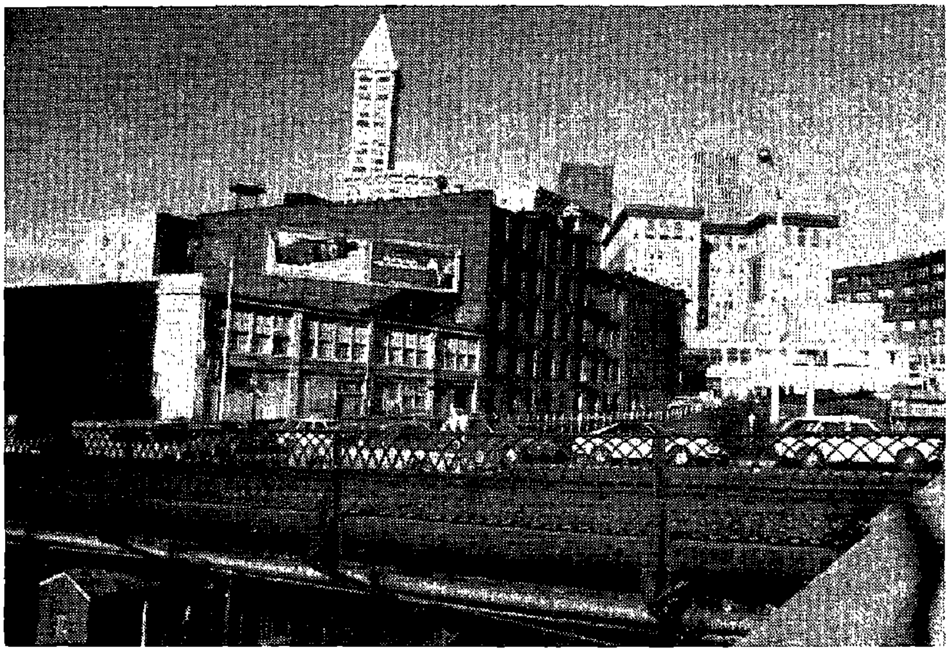

FIGURE 3-59. OVERALL VIEW OF EXISTING URM BUILDINGS
SEATTLE, WA.

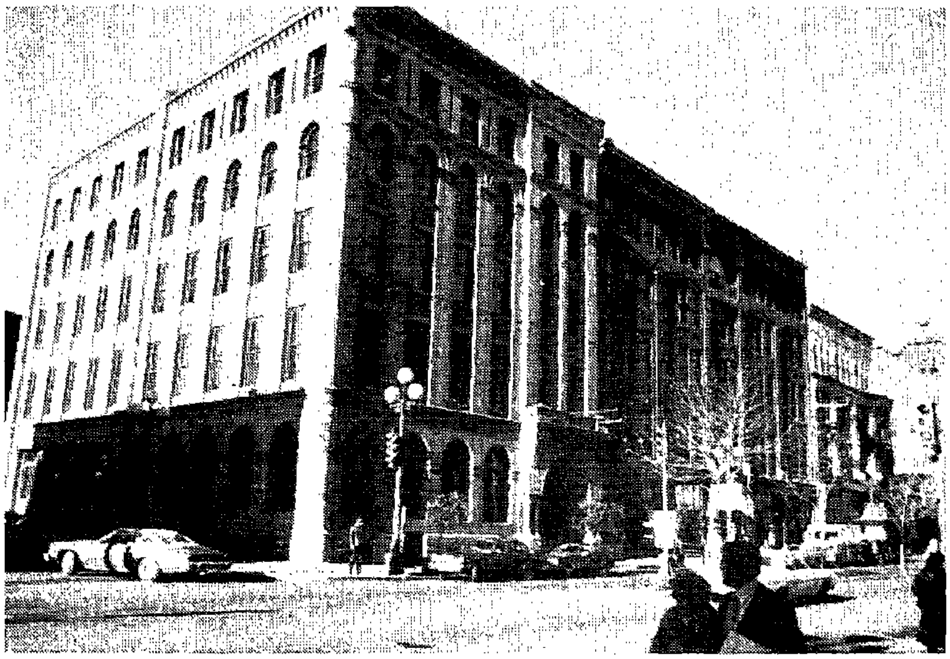

FIGURE 3-60. COMMERCIAL DISTRICT OF URM BUILDINGS
SEATTLE, WA.

FIGURE 3-61. TYPICAL COMMERCIAL URM BUILDING,
SEATTLE, WA.

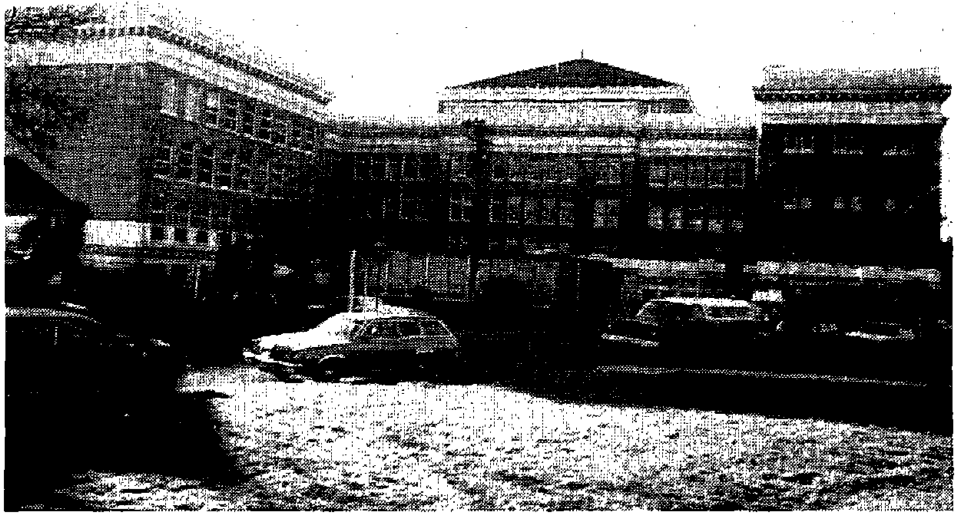

FIGURE 3-62. URM SCHOOL BUILDING,
SEATTLE, WA.

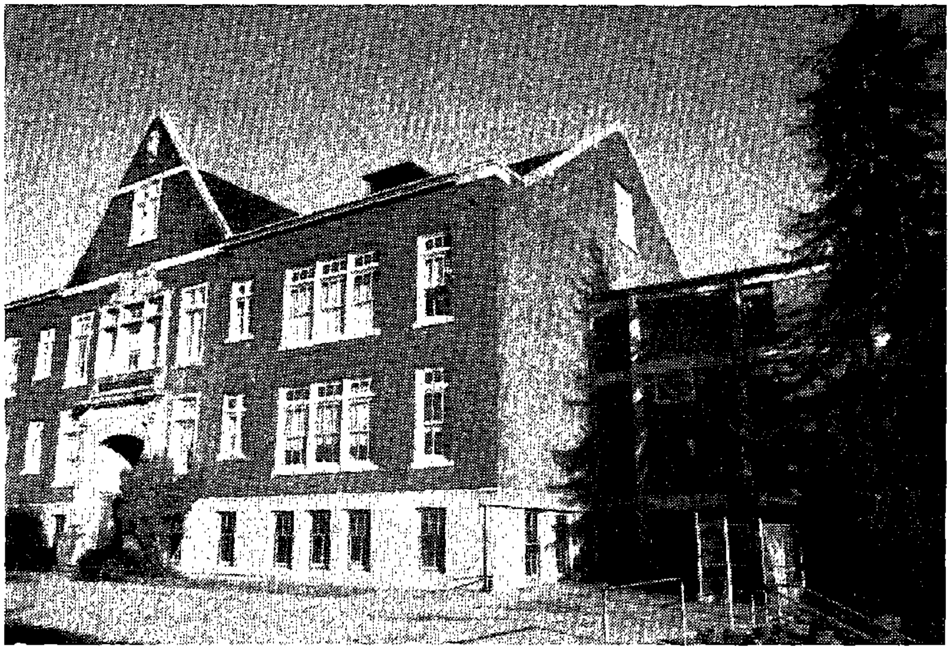

FIGURE 3-63. URM SCHOOL BUILDING, SEATTLE, WA.

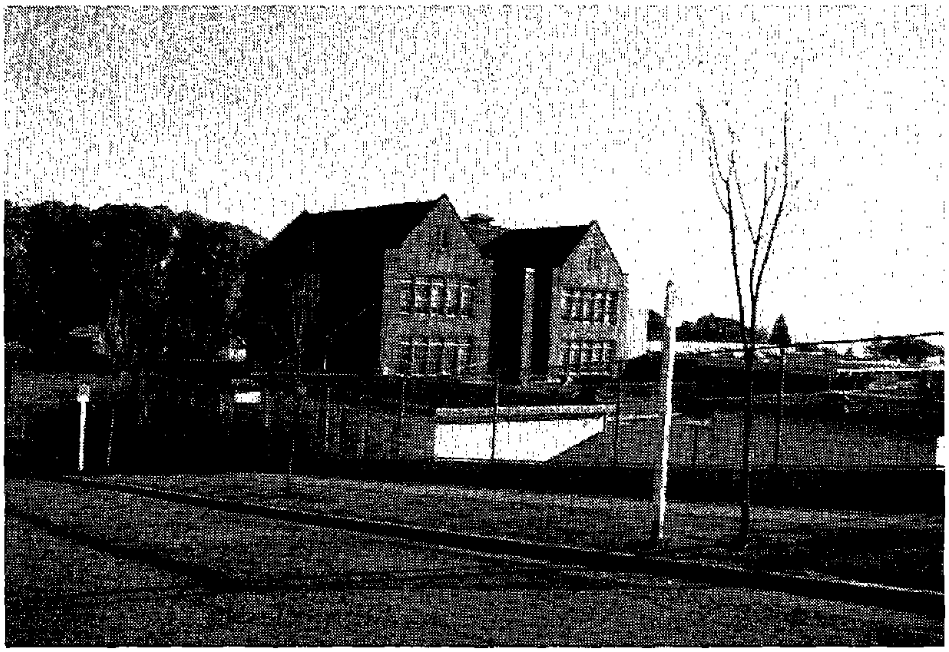

FIGURE 3-64. URM SCHOOL BUILDING, SEATTLE, WA.

The majority of school buildings and commercial buildings in the Puget Sound region utilize wood framing for floors and roofs. The quality of brick is good to excellent and comparable to that in the Wasatch region. The mortar is generally good and weathering is not an extensive problem. Use of terracotta and dressed stone in conjunction with brickwork is common for ornamentation. Entire facades of terracotta and stonework are not common. Reconversion and rehabilitation programs for commercial zones are common in the City of Seattle. URM buildings in these zones have been rehabilitated using standards established by the City of Seattle. These standards require interconnection of URM walls to interior framing as a primary seismic hazard reduction technique. Occupancy of these converted and rehabilitated buildings is estimated to be higher than for comparable commercial buildings in the California coast region.

3.6 CALIFORNIA COAST AND CENTRAL NEVADA REGION

The coastal region extends from the Imperial Valley at the border of Mexico to Eureka on the northern California coast. The major California population centers of Los Angeles and San Francisco lie within this region. This region has the highest zoned seismic intensity in the United States (EPA of 0.4 g). The region of high seismic intensity in central Nevada is sparsely populated, but has URM commercial buildings dating from the era of gold and silver mining. These Nevada and eastern California buildings are typical of the one- and two-story commercial buildings found throughout the western United States.

The California coastal region and the adjacent zones of lesser seismicity have the complete spectrum of URM buildings as described for other geographic regions. In many cities these buildings have been shaken by recorded earthquakes that approximate the seismic hazard region with an EPA of 0.2 g. These cities are El Centro, Brawley, Imperial, San Fernando, Santa Ana, Santa Rosa, South Los Angeles, Long Beach, and Eureka. Ground shaking of an EPA of 0.1 g is common to large areas of the California coastal region and many URM buildings have been subjected to two or more events of this intensity.

Buildings that have been shaken by a seismic intensity somewhat greater than an EPA of 0.2 g are typical of the occupancy use surveyed throughout the United States. The response spectra shown in Figures 3-65, 3-66, and 3-67 (CIT, 1972) were obtained from recordings in the basement of the URM Eureka Federal Building, shown in Figure 3-68. For comparison with the design seismic input (ABK, 1981a) of a region with an EPA of 0.2 g, a dashed line to be compared with the 5% damped spectra is superimposed. A typical office building immediately adjacent to this accelograph site is shown in Figure 3-69. One- and two-story commercial buildings shaken by both the 1940 Imperial Valley earthquake (CIT, 1972) and the 1979 Imperial Valley earthquake (EERI, 1980) are shown in Figures 3-70 and 3-71.

Observed damage reports on URM buildings in this region comprise the majority of available information. However, the reports generally focus on damage and do not investigate the probable reasons for occurrence of damage. Moreover, these reports do not discuss buildings that were not damaged. Buildings photographed for this study have been shaken with the same intensity as those reported with visible damage. In many cases, a quick survey of these buildings would report no damage, or plaster cracking only. Surprisingly, structural deficiencies such as the complete lack of a lateral load carrying system on one or two sides of the building do not cause unsatisfactory performance in regions of strong shaking. Commercial buildings with open fronts such as that shown in Figure 3-72 in the City of San Fernando, as well as all the other open front buildings up and down the block, appear to have been stable when subjected to significant ground displacements. The rear wall of this building, shown in Figure 3-73, does not exhibit damage patterns that would be normally predicted.

Rear walls photographed in other areas of recorded moderate to strong ground shaking exhibit similar minimal cracking. Figure 3-74 shows the rear walls of a group of commercial buildings that were shaken by the 1933 Long Beach earthquake. Figure 3-75 shows a building that has been shaken by both the 1940 and 1979 Imperial Valley earthquakes. Repair of parapet damage that occurred in the 1940 event can be noted in this figure.

FIGURE 3-65

RESPONSE SPECTRUM

EUREKA EARTHQUAKE DEC 21, 1954 - 1156 PST

IIIA008 54.003.0 EUREKA FEDERAL BLDG COMP N11W

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

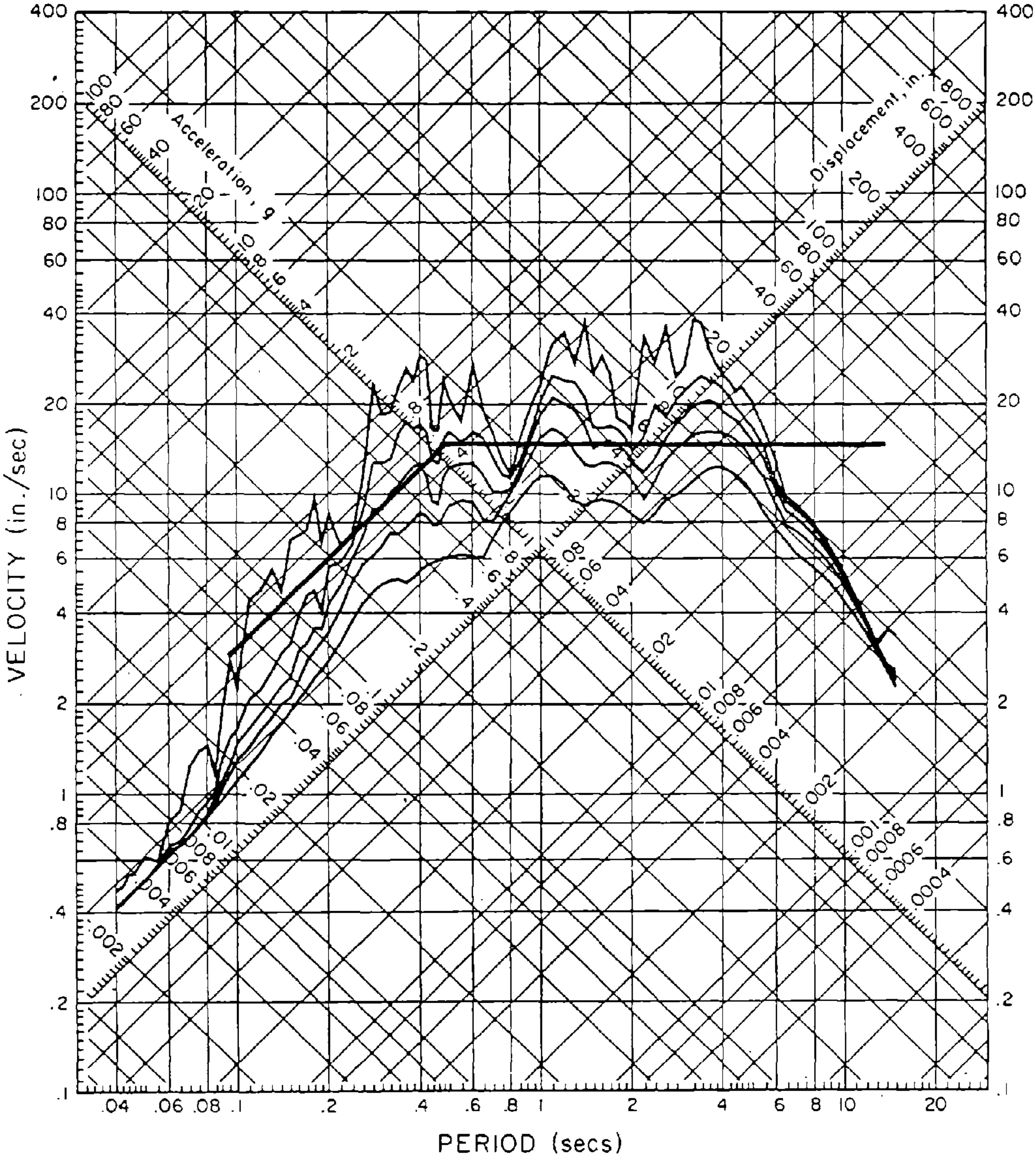

FIGURE 3-66

RESPONSE SPECTRUM

EUREKA EARTHQUAKE DEC 21, 1954 - 1156 PST

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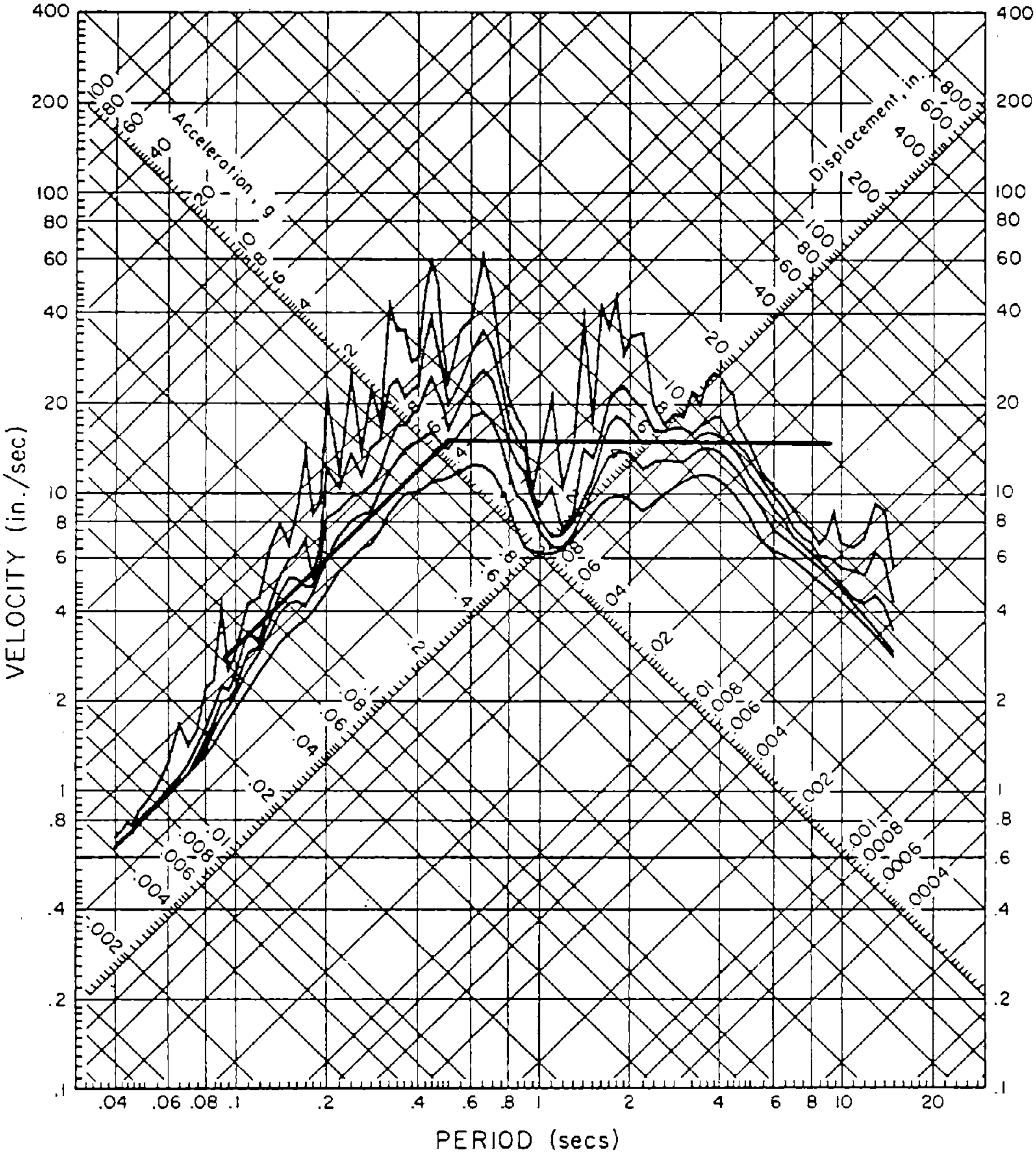

FIGURE 3-67

RESPONSE SPECTRUM

EUREKA EARTHQUAKE DEC 21, 1954 - 1156 PST

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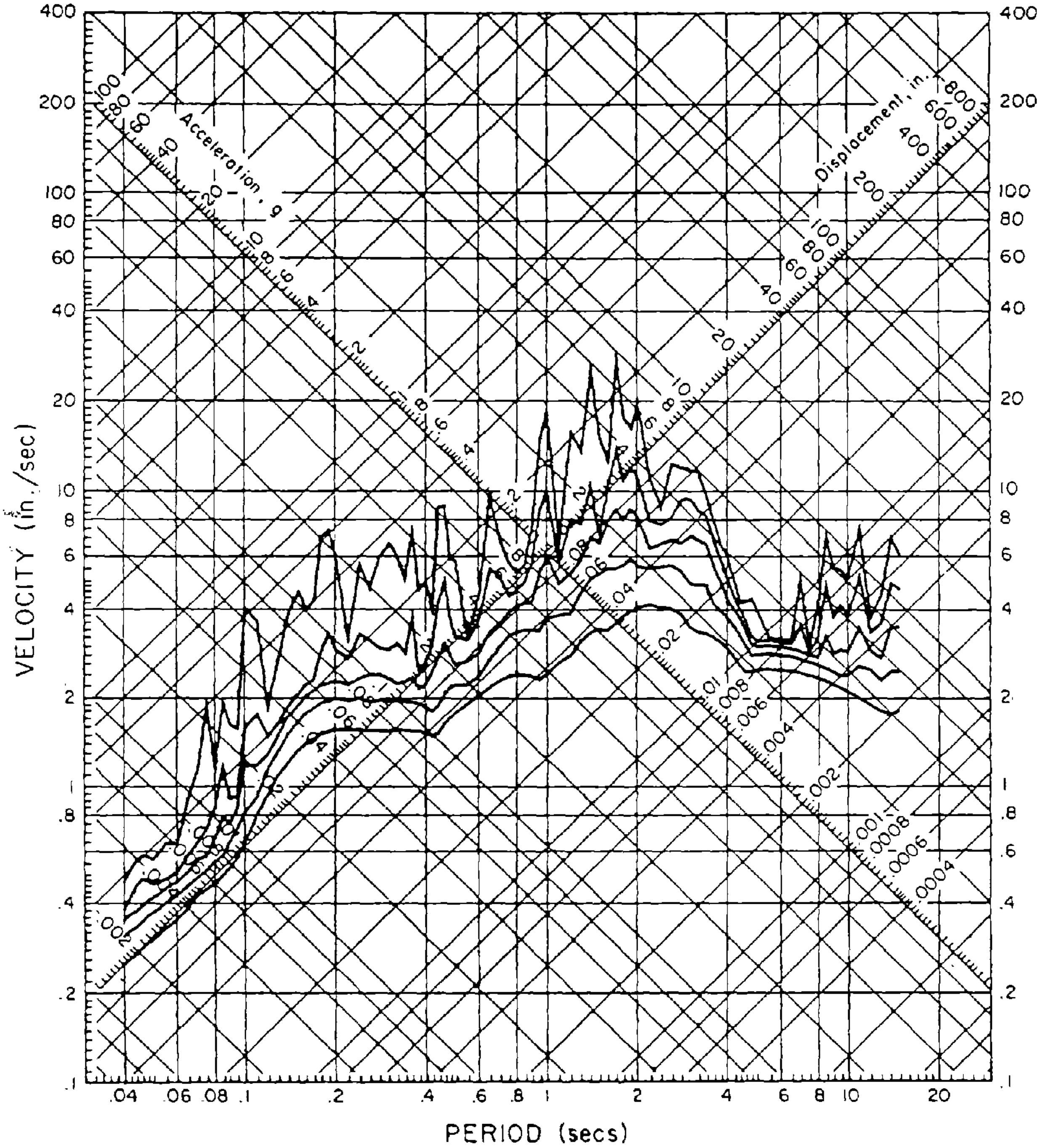

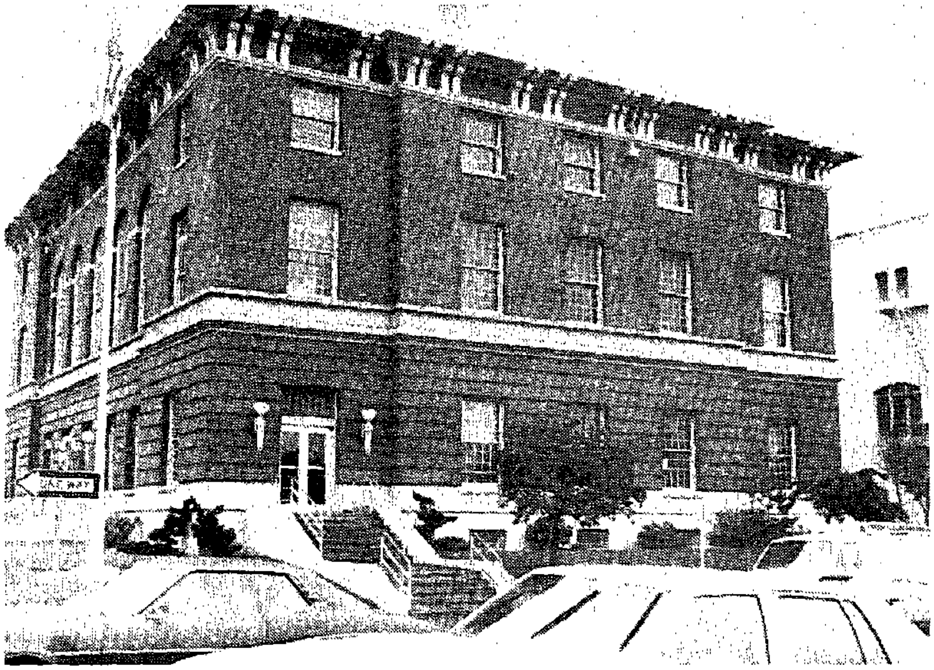

FIGURE 3-68. URM FEDERAL BUILDING,
EUREKA, CA.

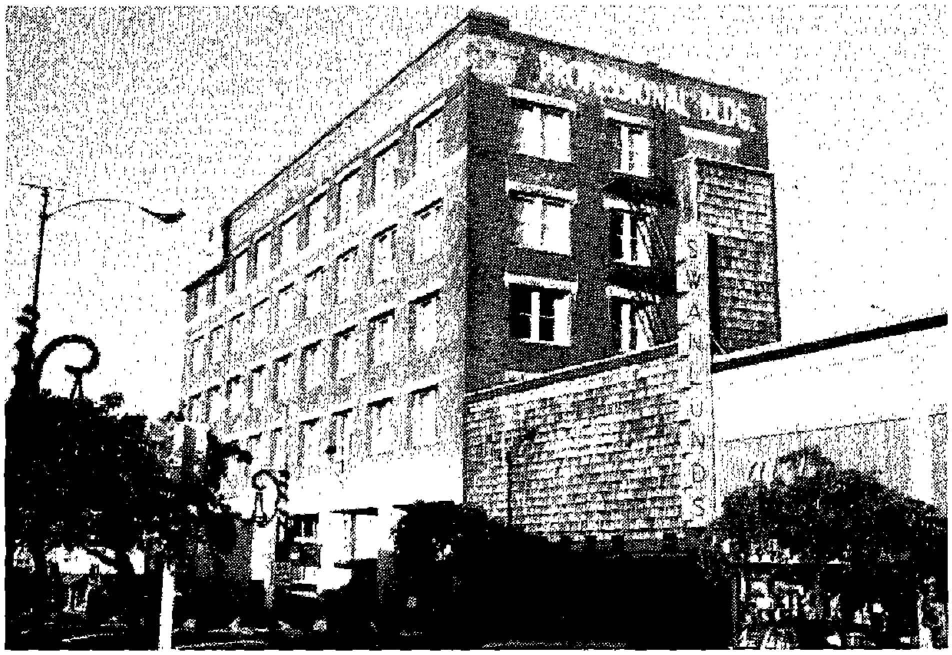

FIGURE 3-69. URM OFFICE BUILDING,
EUREKA, CA.

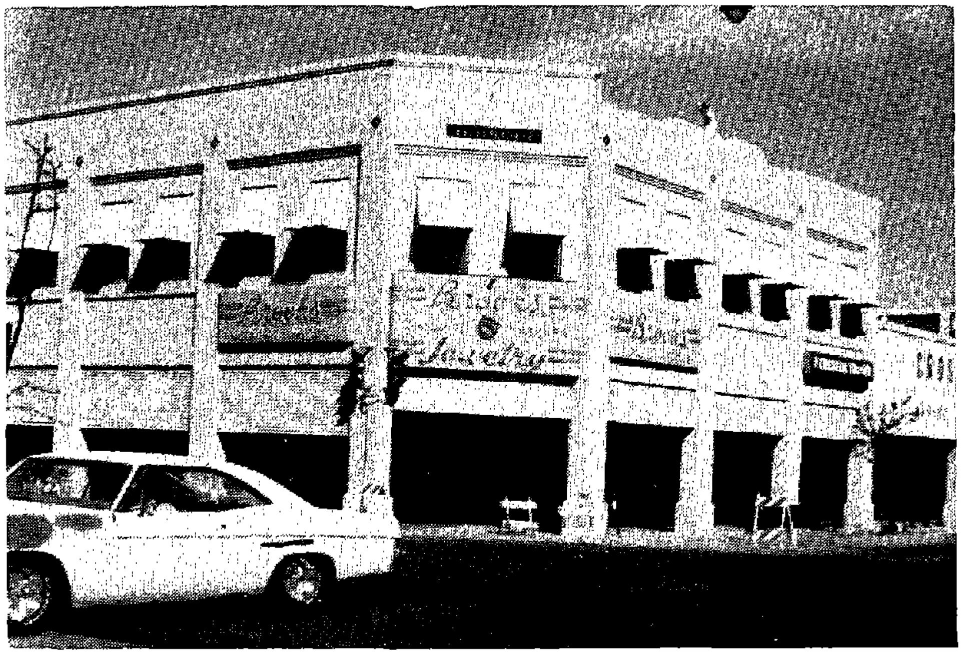

FIGURE 3-70. URM COMMERCIAL BUILDING, EL CENTRO, CA.

FIGURE 3-71. URM COMMERCIAL BUILDING, EL CENTRO, CA.

FIGURE 3-72. OPEN FRONT URM BUILDING,
SAN FERNANDO, CA.

FIGURE 3-73. REAR OF URM BUILDING,
SAN FERNANDO, CA.

FIGURE 3-74. REAR WALL OF COMMERCIAL BUILDINGS, SANTA ANA, CA.

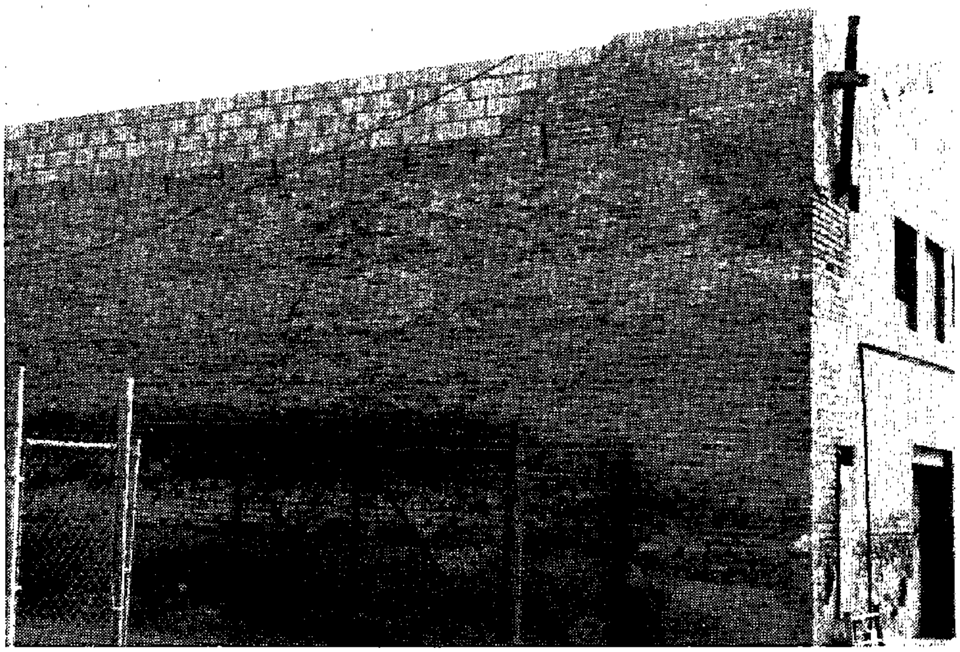

FIGURE 3-75. REAR WALL OF 1940 COMMERCIAL BUILDING, EL CENTRO, CA.

Office buildings in this region range from large to moderate in height and floor space when compared with the eastern half of the United States (Figs. 3-76 and 3-77). Commercial facilities are equal in size and diversity of materials to those examined in the other regions. Figures 3-78 through 3-81 illustrate commercial buildings that are found up and down the entire length of the seismic zone on the Pacific coast. The buildings shown are in San Diego, Los Angeles, San Francisco, and Eureka.

Loft and manufacturing buildings of URM in this region are moderate in size. Apartment buildings constructed of internal wood framing and URM exterior walls have a total of 28,300 dwelling units within the city limits of Los Angeles. The total number of dwelling units in other cities in the Los Angeles basin may equal or exceed that number. The apartment buildings range in size from elaborate structures (Fig. 3-82) to simple rectangular structures (Fig. 3-83).

Public buildings of URM have elaborate facades and irregular shapes characteristic of this category (Fig. 3-84). Some churches approach the size and height of those of the eastern United States (Fig. 3-85) but most are smaller and less ornate.

The average brick quality of the California Coast and Central Nevada region is more vulnerable to weathering than average brick observed in the remainder of the United States. This is attributed by some researchers to the available clays for manufacturing of the brick. Moreover, the mortar varies radically in quality. Sampling of very poor mortar indicates that non-cementitious fines in the sand may be a principal cause of nearly complete deterioration; and what has been termed deterioration due to the presence of lime may have been caused by the unwashed aggregates of the mortar. On the other hand, excellent lime mortars have been discovered in testing of public buildings and important private buildings. This would tend to refute the argument that the quality of the lime was the major contributor to the loss of cementing of the mortar.

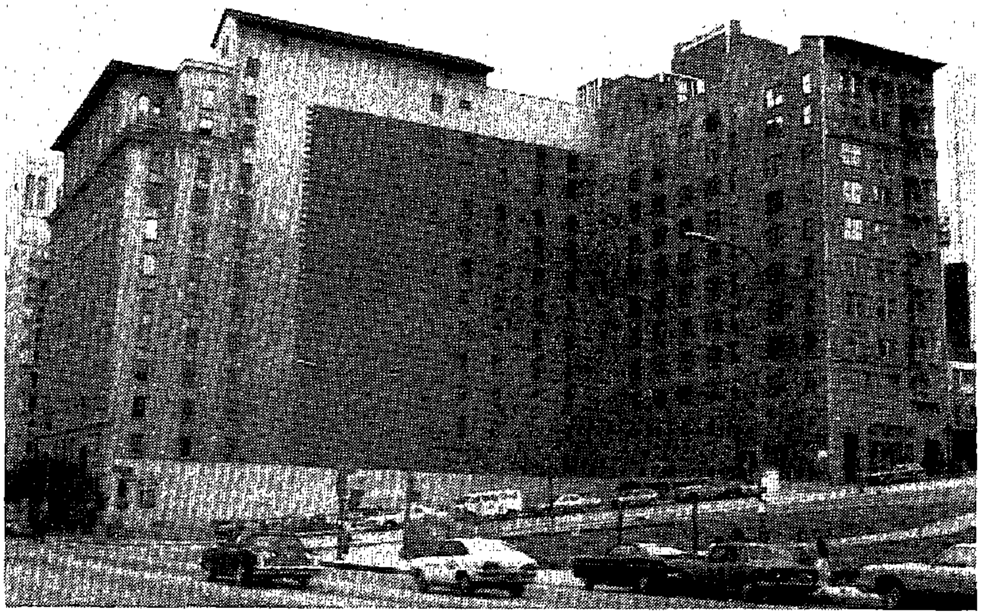

FIGURE 3-76. LARGE OFFICE BUILDING WITH URM WALLS, LOS ANGELES, CA.

FIGURE 3-77. MEDIUM SIZE OFFICE BUILDING WITH URM WALLS, LOS ANGELES, CA.

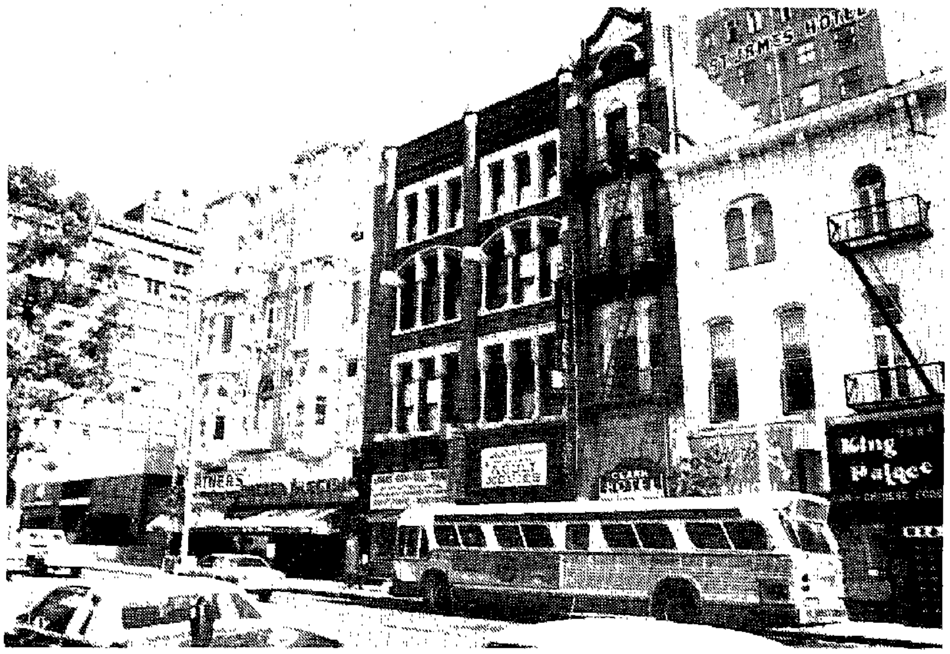

FIGURE 3-78. URM COMMERCIAL BUILDING,
SAN DIEGO, CA.

FIGURE 3-79. URM COMMERCIAL BUILDING,
LOS ANGELES, CA.

FIGURE 3-80. URM COMMERCIAL BUILDING,
SAN FRANCISCO, CA.

FIGURE 3-81. URM COMMERCIAL BUILDING,
EUREKA, CA.

FIGURE 3-82. URM APARTMENT BUILDING,
PASADENA, CA.

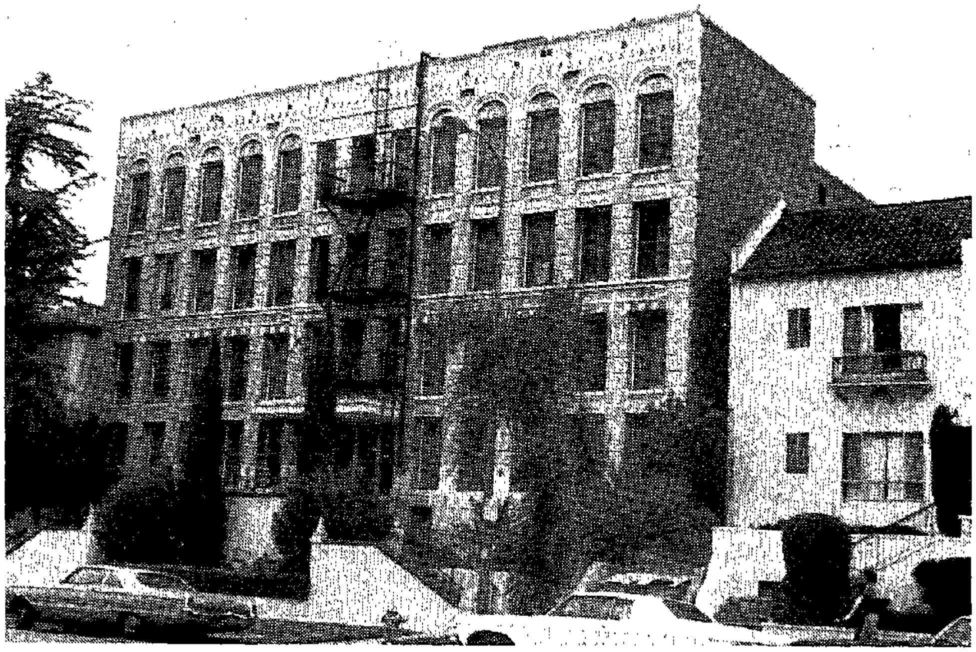

FIGURE 3-83. URM APARTMENT BUILDING,
LOS ANGELES, CA.

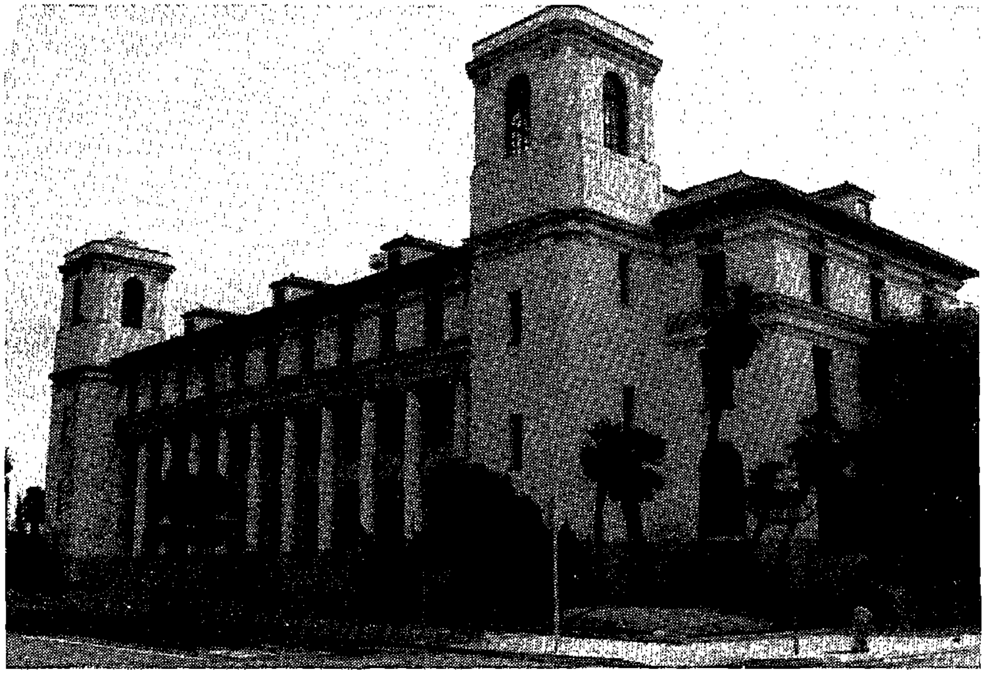

FIGURE 3-84. URM OLD COURTHOUSE, SAN DIEGO, CA.

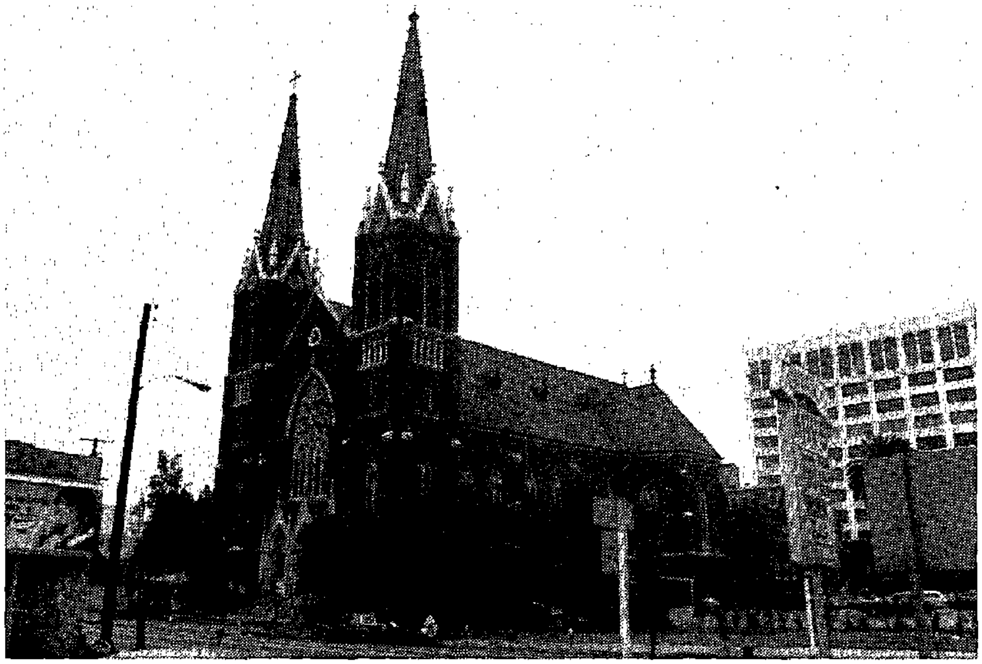

FIGURE 3-85. URM CHURCH, LOS ANGELES, CA.

Anchorage of the internal wood framing to the URM was commonly observed in post-1900 buildings. The common wall anchor observed throughout the United States was a 3/4 inch (19 mm) round bar anchored by an eye-bend to a 3/4 inch round by 9 inch long pin (19 mm x 230 mm) placed between the exterior wythe and the interior wythes. At the wood-framing end, the bar has a 90-degree bend and was commonly driven into a drilled hole in a joist, rafter, or blocking. Wood members framing into a bearing URM wall are commonly anchored at a spacing of about six ft (1.8 m). When the URM wall is parallel to the direction of the wood framing members, the occurrence of anchors was not as frequent and the spacing was generally in excess of six feet.

SECTION 4

CATEGORIZATION OF URM STRUCTURES

4.1 CONSTRUCTION MATERIALS

4.1.1 Significance of Construction Materials

Construction materials observed in the buildings surveyed across the United States included both unique materials and common construction materials. This section on materials is not intended to be a definitive description of all materials that may be observed in a survey made to gather information for a seismic analysis of a specific URM building, but rather to define general classes of construction materials with similar properties that are related to seismic response. Section 1 discussed the relationship of materials and seismic response of URM buildings. The influence of unique materials uncovered in a building by an analyst can generally be related to the influence of common construction materials on the response of a URM building shaken by moderate to strong ground motions. Groupings of common construction materials utilized as building elements are presented in Table 4-1.

4.1.2 URM Walls

Construction materials used for URM walls include manufactured units, natural stone, or cut stone laid in lime or cement-lime mortar. In the South Carolina region, clay was used as mortar in the interior wythes of URM walls in some pre-Civil War buildings. These clay mortars were pointed on the surfaces by lime mortars to minimize erosion of the mortar by rain.

The most common masonry unit observed in pre-1940 buildings is a fired solid clay unit. This common brick is about 2-3/4 by 3-1/2 by 8-1/2 inches (70 mm x 90 mm x 220 mm) in size. Bricks were commonly used to construct the full thickness of the URM walls. Bricks were also used as a backup masonry for architectural cast stone, natural stone,

TABLE 4-1. COMMON URM BUILDING CONSTRUCTION MATERIALS

EXTERIOR WALLS	ROOF	FLOOR	INTERIOR PARTITIONING
1. Solid brick of multi-wythe construction	1. Wood sheathing on wood subframing	1. Multi-layer wood sheathing on wood subframing	1. Nil, or with no significant restraint to interstory displacement
2. Cavity wall construction. Separated wythes of different materials	2. Cast-in-place concrete framing	2. Cast-in-place concrete framing	2. URM walls extending full story height
3. Stone or terra-cotta facing on brick interior wythes	3. Steel decking on steel subframing	3. Concrete fills in steel decking on steel subframing	3. Wood or metal framed partitions with finish materials extending full story height
4. Through-wall units of clay or concrete			

or terracotta exterior facings on URM walls. Natural stone was used much less commonly in interior wythes of brick faced walls and as backup masonry for cut stone facings.

All URM walls have a common materials strength characteristic. These materials have a tensile modulus of rupture much less than their compressive strength. The tensile cracks commonly occur on a mortar-unit interface or within the mortar joint. Interstory displacement resulting from earthquake induced internal forces may cause cracking due to combined axial, flexure, and shear stresses. Shear translation on joint systems within the URM walls may be very disruptive to the axial load-carrying capacity of the wall. If the shear displacement separates the masonry units into an unbonded assembly, behavior under reversing loadings becomes unpredictable. Bonding between wythes of disparate and identical masonry units was accomplished by use of header courses or similar extensions of the unit across the collar joint between wythes. Coursing or overlapping of units within a wythe was nearly universal practice. Large unit architectural facings such as cut stone, cast stone, and terracotta were commonly tied to interior wythes by metal anchors or wire ties.

Brick facings of dense, highly fired units, selected for architectural quality, in the majority of observed instances were not tied to interior wythes by headers (bricks laid with the long dimension across the collar joint). In many buildings of the early 1900's, this exterior wythe is joined to the interior wythes only by the bonding or mortar placed in the collar joint. In subsequent mason's practice, metal ties between wythes supplement the bonding of the mortar. In current practice, the collar joint is commonly clear of mortar, and the bonding between wythes is totally dependent on light gage galvanized metal ties. Current URM walls of this cavity wall construction have the URM exterior facing isolated from the building structure by expansion joints, both vertical and horizontal.

Manufactured concrete or clay units that extend from face to face of the URM wall (through-wall units) are common as infills in multi-story concrete or steel frame buildings, and as bearing or non-bearing walls in small to moderate size buildings. These through-wall URM walls are also common as interior partitioning and as the interior wythe of cavity walls at the building exterior.

4.1.3 Floors and Roofs

Prior to 1900 the great majority of URM buildings used wood sheathing on wood subframing for floor and roof construction. Typical roofs were constructed with a single layer of boards laid perpendicular to the subframing, nailed with a minimum of 2 nails per board at each framing member. Size of the boards was commonly 1x6 to 1x10 nominal. Subframing was rafters, beams, or trusses. Floors were sheathed with multiple layers of 1 inch nominal boards. The layers were laid parallel with the board edges offset from the adjacent layers. In many instances one layer of boards is laid diagonal to the subframing with offset joints between boards. Finish floor materials are commonly dense woods selected for a wearing surface, installed with concealed nailing. These finish floors are boards, edge milled with a tongue and groove joint between the boards. The joint is driven tight and slant nailed through the tongue to the substrata. Nailing to the subframing and between layers is frequent.

In industrial buildings, roofs and floors were of thicker material to obtain more resistance to spread of fire and to allow for abrasion and wear on floor surfaces. These floors and roofs were generally installed on large size wood members spaced further apart than usual joist and rafter systems. The planks used in these industrial buildings are commonly joined by tongue and groove edges and/or doweling driven horizontally through the boards. These details were intended to transfer heavy concentrated loads between the planks.

Single layer floor sheathing of tongue and groove finish boards was observed in mezzanine floors in multi-story buildings built prior to adoption of fire-rating ordinances. Floors using single layer sheathing were discovered in pre-1900 buildings of three stories in height. Post-1900 buildings using a single layer of boards for floor sheathing were frequently observed in two-story buildings and for mezzanine construction.

Cast-in-place concrete floors were commonly observed in public and/or large multi-story structures. Concrete floors were supported by steel beams at the turn of the century and by reinforced concrete beams or steel beams in later years. In the earlier construction the concrete floor construction was cast on the top of the URM wall. The stone or brick facing commonly was continuous on the building exterior, concealing the floor construction. Multi-story buildings with internal steel or concrete frames typically were constructed with the structural framework in place prior to installation of the URM walls. In many of the surveyed buildings, the concrete frame or concrete-encased steel frame is visible on the building exterior (Fig. 4-1). In steel-framed buildings with concrete floors, the URM wall generally conceals the framing to provide weather and fire protection (Fig. 4-2).

Post-1950 URM buildings constructed in seismic hazard regions that do not require design consideration of seismic structural response have wood-framed floors and roofs. However, plywood sheathing, either single- or double-layer, is much more common than board sheathing. Commercial buildings in urban fire districts will commonly use incombustible floor and roof framing for small to moderate size buildings. The URM walls are usually non-bearing, except for minor loads, providing a weather enclosure. However, the seismic response of the URM-walled building is not significantly modified by the provision of a vertical load-carrying frame within the building. This vertical load-carrying frame is commonly structural steel. The floor and roof construction is usually steel decking with concrete fills for floor construction.

4.1.4 Interior Partitioning

Interior partitioning in URM buildings has a significant influence on the seismic response of structures when the partitioning interconnects the floors and the roof. This discussion of the effects

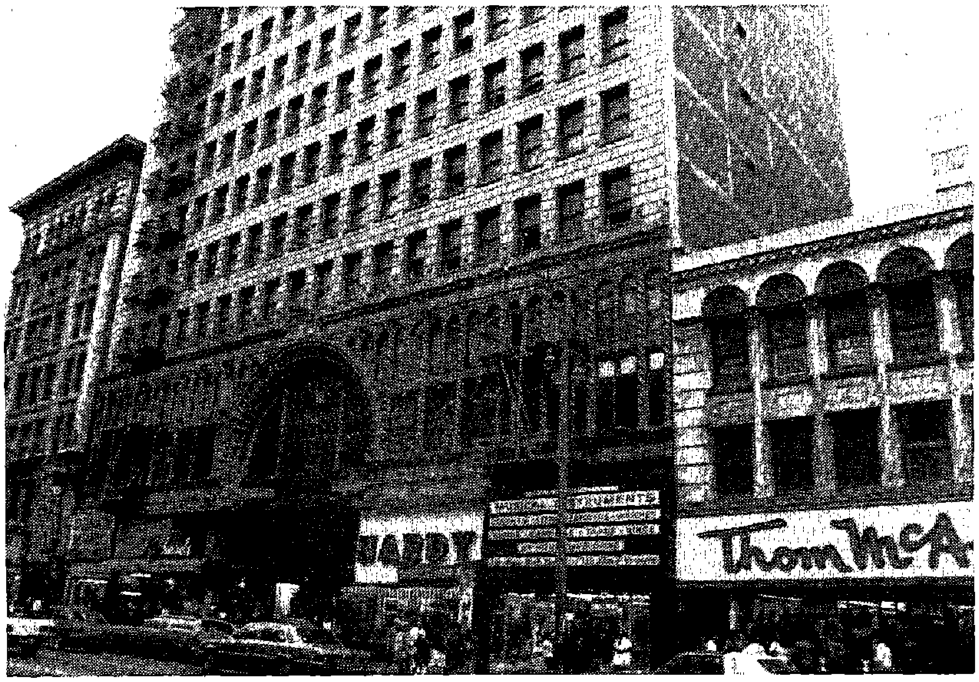

FIGURE 4-1. URM BUILDING WITH VISIBLE STRUCTURAL FRAME

FIGURE 4-2. URM BUILDING WITH CONCEALED STRUCTURAL FRAME

of interior partitioning assumes such interconnection. If an interconnection of finish materials does not exist, the presence of partitioning does not affect seismic response. Partitioning commonly is termed non-structural and its damageability in ground shaking is given little consideration, as its in-plane cracking rarely constitutes a life-safety hazard. However, full-height partitioning in a story level can provide a very substantial resistance to interstory displacement.

Occupancies such as multi-family housing are subdivided into small spaces by full-height partitioning, commonly wood frame walls, sheathed with finish materials attached to the framing by nails. Interstory displacements in excess of the elastic capacity of the finish materials and their fastenings will cause cracking and inelastic displacement with insignificant life-safety threats. Cyclic tests on these wall systems indicate that the inelastic resistance capacity is generally maintained on reversal and reloading cycles.

These inelastic properties of internal full-height partitioning indicate their ability to limit a possible undamped response of horizontal floors and roof diaphragms. In many cases the partitioning may have adequate elastic strength to transmit ground motions to the upper stories. These possible paths for inertial forces will supplement the in-plane capacity of the URM walls, and may significantly diminish the need for horizontal elements such as diaphragms to control in-plan relative displacements.

Interior partitioning is commonly wood-framed walls with finish materials such as plaster on various types of laths in buildings with wood-framed floors and roofs. Interconnection of the partitioning to the floor above is typically through minimal nailing and continuity of the finish materials. Connection of the partitioning at the floor is commonly by direct nailing of the partition sill to the floor framing. If finish wood flooring is used, the flooring commonly abuts the sill, providing resistance to relative displacement. In URM buildings of incombustible construction, the interior partitioning will probably be metal stud framing with finish of plaster on metal lath. Alternative partitioning will be unreinforced gypsum or clay tile walls commonly plastered on each face.

In many large size buildings, URM walls subdivide the interior space for containment of fires. These fire walls are typically full height and have minimal openings in any story.

4.1.5 Summary of Common URM Building Construction Materials

Table 4-1 lists common construction materials used in existing URM buildings throughout the United States. Although other combinations of materials and unique materials were observed in the survey, in each exception to the common constructions, the material observed can be related to the seismic performance characteristic of the listed common materials.

4.2 SIZE OF URM BUILDINGS

4.2.1 Height of URM Buildings

The tallest URM buildings were surveyed in urban areas developed after 1900 (Fig. 4-3). Ten to twelve stories is the common upper bound in height. The majority of commercial URM buildings are two to five stories (Fig. 4-4). Recently constructed single-story URM buildings are common in regions not requiring seismic design considerations. Post-1950 buildings using URM as part of the structural frame generally do not exceed two stories in height.

4.2.2 Plan Size of URM Buildings

The plan size of URM buildings varies from the very large manufacturing and industrial buildings with plan dimensions of over 400 ft (122 m) such as that shown in Fig. 4-5, URM hotels occupying a full city block (Fig. 4-6), to the much more typical urban commercial development with dimensions equal to ordinary city lots of 40 to 60 ft (12 to 18 m) wide by 100 to 150 ft (30 to 46 m) deep (Figs. 4-3 and 4-4). Manufacturing and industrial buildings are rectangular to nearly square. Very large

FIGURE 4-3. POST 1920 URBAN CENTER OF URM BUILDINGS

FIGURE 4-4. TYPICAL COMMERCIAL DEVELOPMENT OF URM BUILDINGS

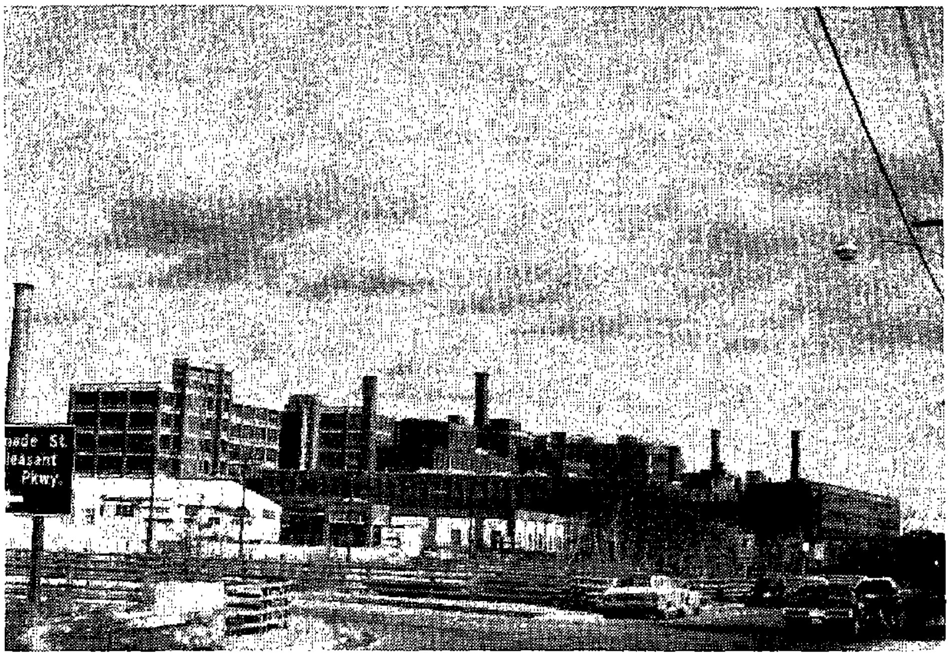

FIGURE 4-5. LARGE INDUSTRIAL URM BUILDINGS, NEW ENGLAND REGION

FIGURE 4-6. LARGE URM HOTEL, PASADENA, CA.

office buildings (Fig. 4-3) are rectangular with the larger dimension exceeding the smaller by about a factor of three. Large hotels and offices may be rectangular at grade but are divided into wings above the lower floors to provide light and ventilation to interior space (Figs. 4-7 and 4-8).

Public buildings are generally moderate in height, two to four stories, but irregular in plan (Fig. 4-9). Colonnades or large porticoes are common (Fig. 4-10). In many cases elaborate gables and spires extend above the roof line (Figs. 4-11 and 4-12).

4.2.3 Categorization of Size of URM Buildings

The categorization of the size, both in height and plan dimension, of URM buildings shown in Table 4-2 is intended to indicate the most common range of size. The seismic response of a URM building can generally be related to its number of stories. Plan dimensions are not closely related to response of rectangular URM buildings, as a near linear relationship exists between effective earthquake response mass and the limit of elastic behavior of the horizontal elements when displaced by horizontal inertial forces.

TABLE 4-2. CATEGORIZATION OF COMMON SIZES OF URM BUILDINGS

Height given in number of stories	Plan dimensions in feet (m)
1. Single story	1. 40 x 100 ft (12 x 30 m)
2. Single story with very high story height. Towers and steeples attached.	2. 60 x 150 ft (18 x 46 m)
3. 2 to 4 stories	3. 100 x 300 ft (30 x 91 m)
4. 5 to 7 stories	4. Greater than 200 x 400 ft (61 x 122 m)
5. More than 7 stories	5. Irregular in plan with multiple wings off central core

FIGURE 4-7. LARGE URM BUILDING WITH MASONRY WALLED WINGS ABOVE FIRST LEVEL

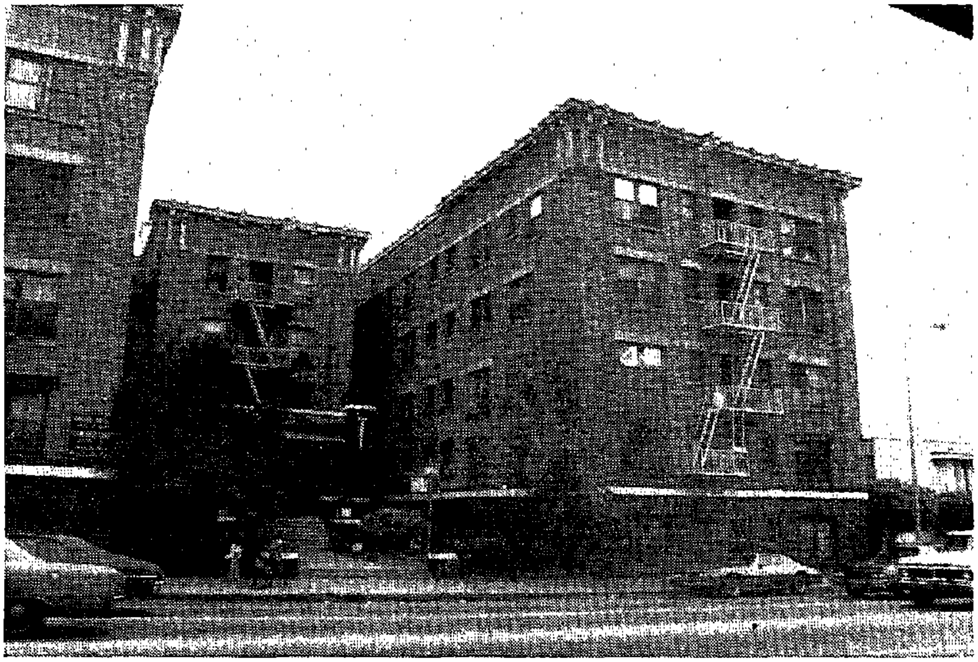

FIGURE 4-8. LARGE URM APARTMENT BUILDING WITH WINGS OF VARIABLE SIZE

FIGURE 4-9. COUNTY OFFICES, MEMPHIS, TN.

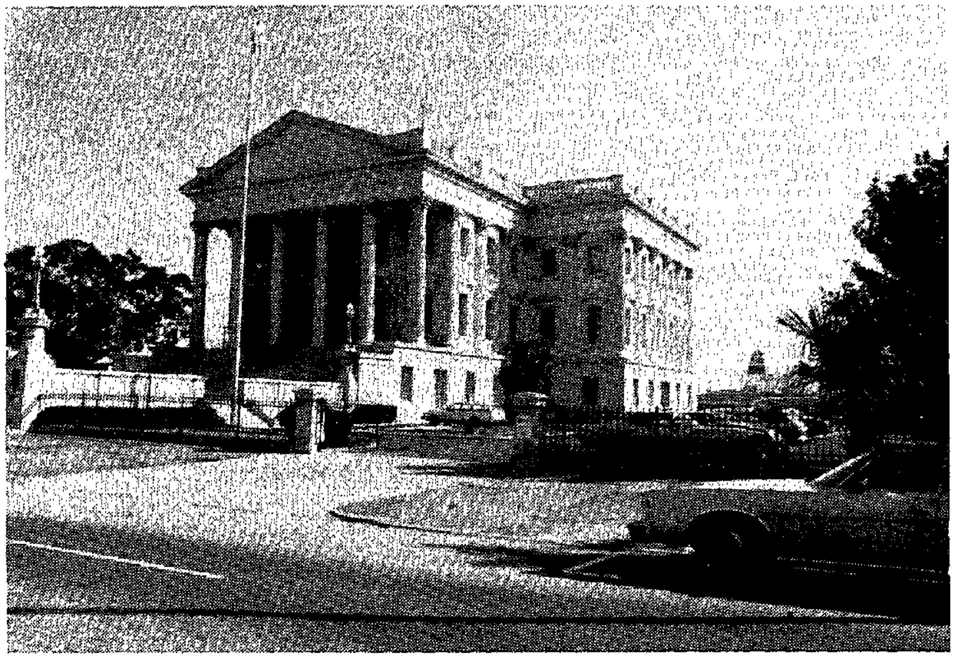

FIGURE 4-10. OLD CUSTOMHOUSE, CHARLESTON, SC.

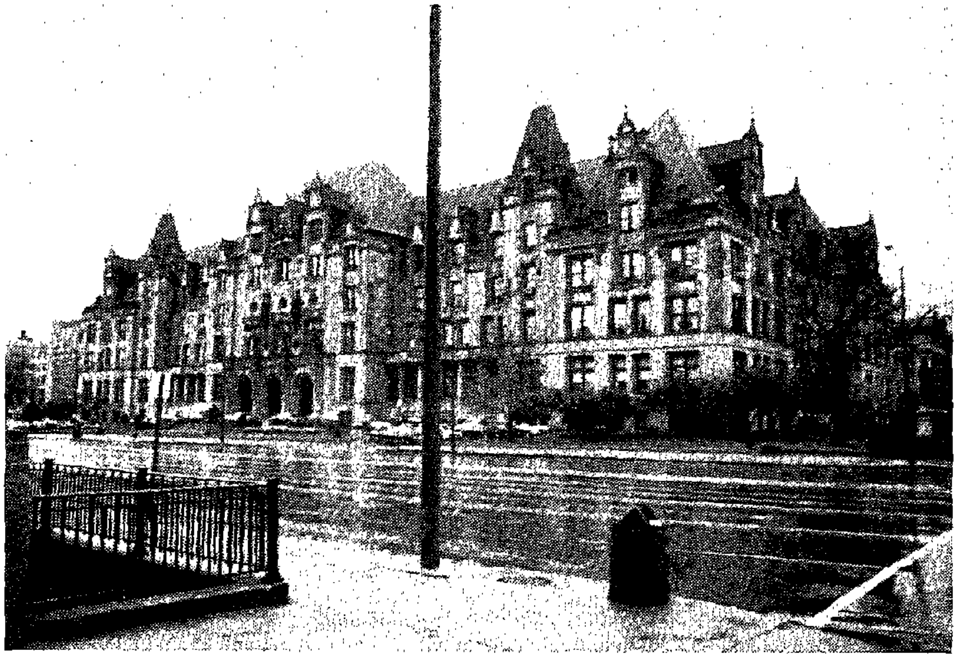

FIGURE 4-11. CITY HALL, ST. LOUIS, MO.

FIGURE 4-12. STATE HOUSE, NEW HAVEN, CN.

4.3 DISTRIBUTION OF URM WALLS

Designers of current buildings in moderate to high hazard seismic zones generally believe that symmetry of the lateral load-resisting system about the plan center of building mass is very desirable for good seismic performance. Existing URM buildings, in most instances, violate this accepted design principle. URM walls were built in urban areas, primarily for their resistance to the spread of fire from building to building. To limit fire to the single building in which it started, fire regulations generally required solid URM walls on lot lines between adjacent properties.

Exterior walls could have openings for both light and ventilation, if the walls were set back from the property line a distance specified in the fire regulations. At the street frontages, openings to the building interior were not limited except for the requirements of structural support. At the rear, either facing the rear portion of the lot or an alley, openings required for the use of the building were permitted. Figures 3-73 and 3-74 show rear views of commercial structures that have been shaken by moderate to strong ground motion. Figure 4-13 shows a typical alley in the New Madrid region. These buildings have solid URM walls on the property lines between the stores, as can be seen over the roofs of the lower buildings in Figure 4-14, and very minimal URM walls at the first-story street-front. The solid wall on the near building is likely a recent renovation and conceals the original building front. The addition is probably a plaster finish over light framing. Typical street front fenestration can be seen on the two adjacent multi-story buildings.

Large URM buildings of industrial or manufacturing occupancies are set back from property lines and have a large percentage of openings on the exterior walls for light and ventilation (Fig. 4-15). Figures 4-7 and 4-8 illustrate a similar penetration of the exterior walls that is typical of large multi-family housing units. Both of these buildings have interior fire walls compartmentalizing the combustible interior framing into specified areas. The spacing of the interior fire walls

FIGURE 4-13. REAR OF COMMERCIAL BUILDING, MEMPHIS, TN.

FIGURE 4-14. VIEW OF STREET FRONTS OF COMMERCIAL BUILDINGS, MEMPHIS, TN.

FIGURE 4-15. INDUSTRIAL BUILDING,
NEW ENGLAND REGION

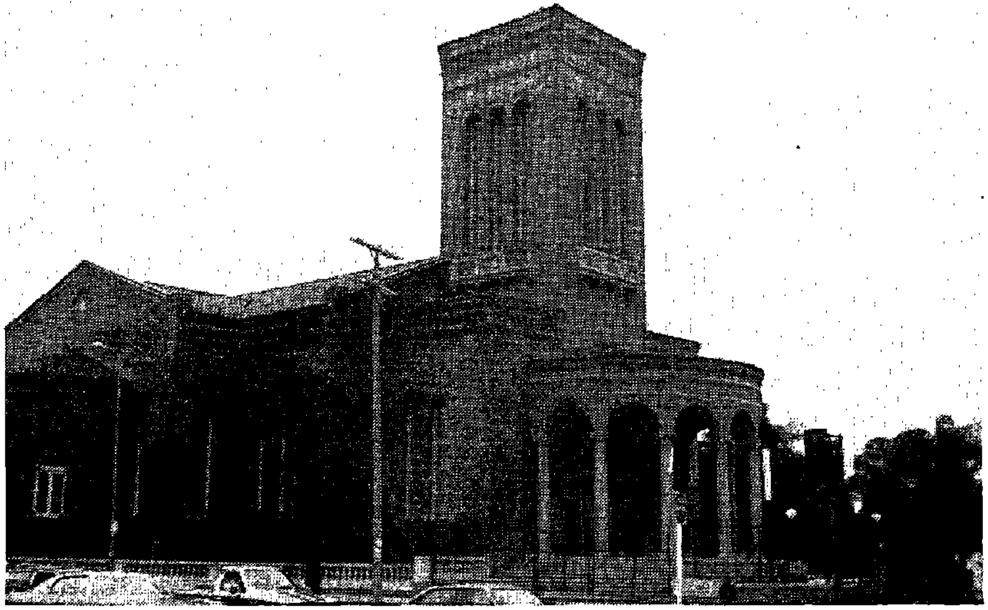

FIGURE 4-16. CHURCH BUILDING, LOS ANGELES, CA.

varies in accordance with fire regulations, but generally has a spacing of 60 to 100 ft (18 to 30 m) in all stories.

Public buildings, as shown in Figures 4-9 through 4-12, have the exterior URM walls at the perimeter extensively fenestrated and are irregular in plan. However, these structures commonly have concrete floors framing into interior URM walls. The spacing of these interior walls may vary from all walls being used for room subdivision to walls that outline public corridors, lobbies, and other public areas. These interior walls, in many instances, will be the principal elements controlling interstory displacement during earthquakes.

Churches and similar public assembly occupancies (Figs. 3-85 and 4-16) have URM walls in a rectangular pattern around the large assembly area. However, exterior spaces are appended to the basic structure in many different shapes and heights. Seismic response of these buildings will be as an assembly of parts rather than a coherent unit. The interconnection of spaces adjoining the main body of the structure will require a complex analysis and retrofit program.

Table 4-3 gives general descriptions of the distribution of URM walls in the buildings surveyed throughout the United States. This table is not intended to be a fully definitive classification according to building occupancy; only a survey of each building considered in an earthquake hazard reduction program will determine the specific configuration of URM walls. Table 4-3, in conjunction with the other descriptions (i.e., construction materials, size, and interconnection of parts) will be used to give a general categorization of the large majority of URM buildings.

TABLE 4-3. DESCRIPTOR FOR DISTRIBUTION OF URM WALLS IN BUILDINGS SURVEYED

1. URM walls at perimeter. Building plan rectangular to near square. Fenestration reasonably uniform at exterior.
2. As above and with interior URM walls on a reasonably uniform pattern.
3. URM walls at perimeter. Building plan rectangular with long dimension exceeding least dimension by more than two. Nearly full building width openings at street frontage (may be on two adjacent sides at street corner). Penetration of exterior walls non-uniform.
4. Distribution of URM walls in an irregular plan pattern at building perimeter. Distribution of URM walls within building perimeter in an irregular pattern.
5. Distribution of URM walls in irregular plan pattern. Additional URM walls enclosing adjacent different story height spaces in an irregular pattern.

4.4 INTERCONNECTION OF ELEMENTS OF URM BUILDINGS

In the planning of the nationwide survey, a variability of construction practices among the regions was originally assumed; however, the survey revealed that a regional influence was not a factor. Rather, an orderly progression of construction practices was noted. Masonry construction originated in the early settlements on the Atlantic coast and, as the population moved westward, construction techniques common to the era moved with the flow of commerce. Many cities had a surge in growth during a boom era, and the majority of existing URM buildings will be typical of an era, such as the 1880's in San Diego's Gaslight District. Other cities, such as St. Louis, have a progression of URM buildings that reflect the changes in practice from the early 1800's to current times.

Interconnection of elements of the URM buildings was not a common practice, even in areas of the California Coast and Central Nevada region. After damaging earthquakes these areas were rebuilt using pre-earthquake methods in the California region up to the 1933 Long Beach earthquake. After this earthquake, URM was banned as an acceptable construction material. URM was prohibited as a construction material in the Puget Sound and Wasatch regions in the early 1960's, as awareness of the regions' seismicity increased. When seismic design for severe or moderate ground shaking was mandated, interconnection of parts and elements of the building became common, and construction of URM as part of the building structure ceased.

The total inventory of URM buildings surveyed across the United States have little or no designed interconnection of parts of the buildings. However, the use of ties of the URM walls to the internal framing is more common than lack of ties. These ties were for the purpose of supporting a fire wall, rather than to resist cyclic earthquake forces. Ties are much more frequent for bearing walls than for walls paralleling the floor framing and, unfortunately, less common and more erratically spaced at the roof level than at the floor level.

Interconnection of the edges of floor and roof framing, except for a tension tie perpendicular to the wall as previously discussed, is generally completely omitted in the URM buildings observed. When concrete floors were used in URM bearing wall buildings, the concrete was placed on top of the interior wythes, allowing the architecturally selected materials to have continuity on the building face. The reinforcement in the concrete construction commonly stopped very near to the face of the URM wall, leaving only an unreinforced concrete tie. In later practices when a concrete or steel frame was used to support the floors, the URM was infilled into the frame after the frame was constructed. Connection at the base of the infilled wall is generally accomplished by a mortar joint, at the vertical edge by light ties or a mortar joint, and the top edge is typically unattached with the open joint filled from the surface by finish materials after the installation of the topmost masonry unit.

Table 4-4 gives a general description of the common practice for interconnections of elements in the URM buildings surveyed.

TABLE 4-4. INTERCONNECTION OF ELEMENTS OF URM BUILDINGS

1. URM walls tied to floors and roofs, perpendicular to wall.
2. As above, and with interior partitioning interconnected to horizontal framing by finish materials.
3. Little continuity or ties between URM walls and horizontal framing, or interior partitioning and horizontal framing.

4.5 ORIGINAL DESIGN CRITERIA

In the planning for the categorization survey, it was assumed that URM buildings designed for lateral loads, even design lateral loads other than those used for earthquake design criteria, would have significant differences from non-designed buildings. This assumption proved to be invalid, in that URM was considered ineffective in modifying the possible lateral displacement of a designed structure. Adoption of any seismic design criteria generally prohibited the use of URM. Therefore, a sharply defined break in use of URM construction generally occurred once seismic design practices were adopted.

Studies of design practices used in the United States for URM indicate a consistency of non-design for URM throughout the United States. The URM was constructed prior to lateral load design requirements or in the absence of a consistent and rational lateral load design requirement.

4.6 SUMMARY OF CATEGORIZATION

This section will present a summary of the categorization of the URM buildings surveyed by the identifiers previously described. The summary will use occupancy as the key description that may be related to the generalized categories given in Tables 4-1 through 4-4.

The survey confirmed its original premise, that occupancy provides the common tie between buildings surveyed from the Atlantic to the Pacific coast. The reason for this is straightforward. Commercial space in an urban center serves identical purposes throughout the United

States. Housing needs are reasonably identical without regard to geographical region. Only the time of construction modified the style. The architectural style of the 1880's differed from that of the 1920's, but each era was reasonably identical in all geographic regions.

Materials used in geographic regions vary somewhat. The Puget Sound region commonly uses wood framing in large URM buildings due to its availability. Very large manufacturing buildings in URM are rare west of the Rocky Mountains simply because the developing economy did not require such buildings. The summation of the categorization shown in Table 4-5 describes the characteristics of the majority of the occupancies of URM buildings surveyed in the United States. As discussed previously, each of these characteristics can be related to probable seismic response. Continuing studies of the structures selected, as representative of each category, will examine the influence of each identifier. Identifiers that have a negative influence can then be used to establish priorities for earthquake hazard mitigation programs.

In Table 4-5 the numerical identifiers from Tables 4-1 through 4-4 are used to describe each common URM occupancy. These descriptions do not imply that other construction types do not exist, rather that the majority of buildings fit these descriptions. When two identifying numbers are listed for an occupancy, it indicates that a large number of buildings having each characteristic were discovered in the survey. The sequence of the identifying numbers indicates the order of commonality.

TABLE 4-5. SUMMARY OF CATEGORIZATION SURVEY

OCCUPANCY OR USE CATEGORY	TABLE 4-1 CONSTRUCTION MATERIALS				TABLE 4-2 SIZE		TABLE 4-3 DISTRIBUTION OF URM WALLS	TABLE 4-4 INTERCONNECTION OF PARTS
	URM WALLS	ROOF	FLOORS	INTERIOR PARTITIONS	HEIGHT	PLAN SIZE		
Industrial buildings	1	1	1,2	1,2	3,4	3,4	2,1	1,2
Public schools	1,3,2	1	1,2	3,2	3	2,5	1,4	1,3
Public buildings	3,1	1	2,1	2,3	3	3,5	4	2
Apartments/hotels	1,2,3[a] 1,2,3[a]	1 1	1 2	3[c] 3[c]	3,4 5	1,2 5,2	1 4[b]	2 2[c]
Commercial/office buildings	1,3[a]	1 1	1 1 2	3[c] 3[c] 3[c]	3 4 5	1,2 2 2,5	3 3 3,4[b]	2[c] 2[c] 2[c]
Churches	3,1	1		1	2	5	5	3
Post-1950 industrial	2,4	3,1		1	1	3,4	1	3
Post-1950 commercial	2,4	3,1	3,1	1	1,3	2,3	3	3

a. At street front
b. With interior courts for light and ventilation above first floor
c. In stories above first floor

SECTION 5

SELECTION OF STRUCTURES

5.1 SELECTION OF REPRESENTATIVE STRUCTURES FOR ANALYSIS

Structures that are representative of a significant number of the URM buildings in the United States have been selected for analysis by the methodology for mitigation of seismic hazards in existing unreinforced masonry buildings (ABK, 1982b). The selected buildings include both existing structures and composite structures. The composite structures are similar in size, materials, and other characteristics to many buildings indigenous to a seismic zone or common throughout the United States. This research program will be able to compare its recommendations with those of other programs, where different techniques or ordinances were used to analyze some of the same types of buildings for the mitigation of seismic hazards; significant differences in recommendations will be examined in detail. In addition, the analyses performed in accordance with the methodology will be used as examples in a presentation of the methodology during the utilization phase. The selected structures are described in the following sections.

5.2 INDUSTRIAL BUILDINGS

Two six-story industrial buildings, similar in plan, size, and height to the one shown in Figure 5-1, have been selected for analysis to determine the seismic hazards. The plan size of the buildings selected is 70 by 360 ft (21 by 110 m), and the story neight is 11 ft (3.3 m). A moderately pitched wood-framed roof is assumed. Heavy plank floors on wood beams, girders, and columns will be used as one example. A concrete floor will also be considered as a common floor construction alternative to the wood framing. URM fire walls will subdivide the building into 45 to 70 ft (14 to 21 m) bays. Anchorage of the exterior walls to only the girders and floor beams framing into the bearing URM walls will be assumed. Spacing of the typical rod anchors of 8 ft (2.4 m) will be assumed.

FIGURE 5-1. CONVERTED URM LOFT BUILDING
NEW ENGLAND REGION

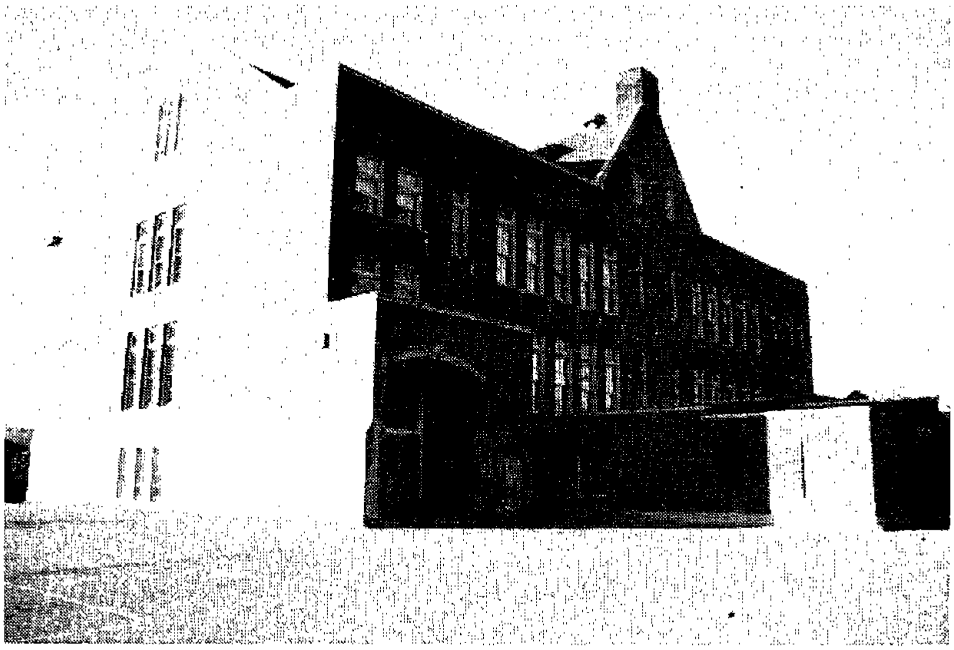

FIGURE 5-2. FRONT VIEW, URM PUBLIC SCHOOL
PUGET SOUND REGION

For the purposes of this analysis, these two representative buildings will be assumed to be sited in a seismic zone with an EPA of 0.1 g.

5.3 PUBLIC SCHOOLS

Figures 5-2 and 5-3 illustrate a common URM school building of the early 1900's. The building has three stories and is about 90 by 150 ft (27 by 46 m) in outside dimensions. The single-story addition shown in Figure 5-3 is of recent construction.

The high-pitched roof is framed by a single layer of boards laid over lightly framed wood trusses. Floor framing consists of a subfloor of boards with a finish wood floor laid over wood joists. Plaster ceilings are applied directly to the underside of the attic ceiling joists and the floor joists. The first floor walls are lightly reinforced concrete walls with URM walls above. The large gable ends and the URM walls are not anchored to the interior floor framing. All interior walls subdividing the classrooms and corridors are plastered wood stud walls with minimal openings.

For the purpose of this analysis, this representative building will be assumed to be sited in a seismic zone with EPA of 0.2 g.

5.4 PUBLIC BUILDINGS

A representative public building selected for analysis is shown in Figure 5-4. The building is about 90 by 136 ft (27 by 41 m) in outside dimensions. Story heights vary from 12 ft (3.6 m) at the lowest story to 19 ft (5.8 m) at the upper story. Floors are concrete placed over heavy gage metal lath supported on steel beams. The roof is wood framing supported by steel trusses. The lower two stories are subdivided into working spaces by URM walls; the upper story has large courtroom spaces with URM walls at the central lobby only.

The thickness of the exterior walls, constructed of sandstone with brick backup, is 19 to 23 inches (0.5 to 0.6 m) at the upper and

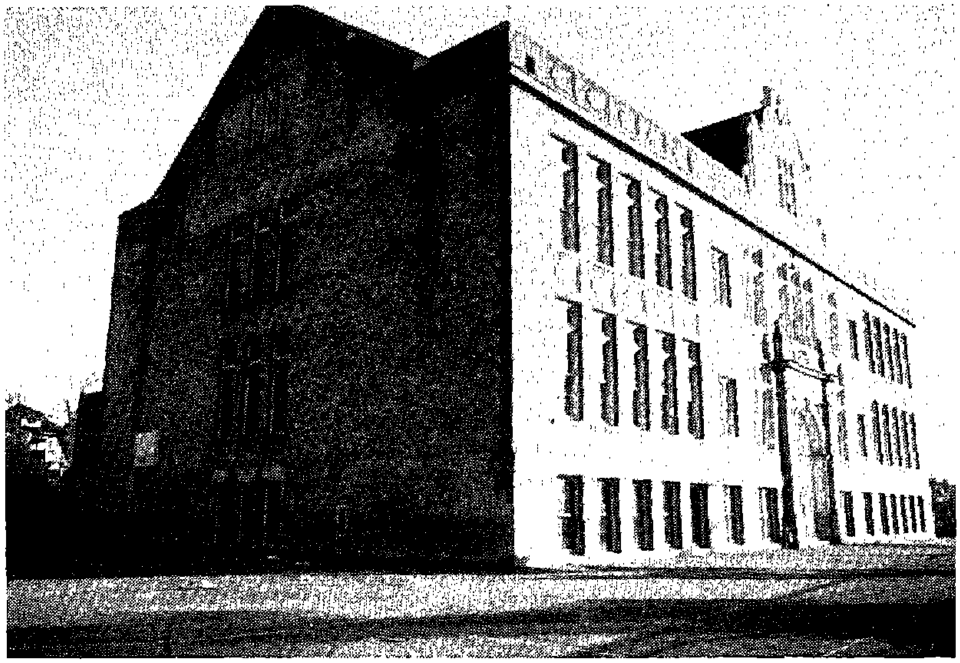

FIGURE 5-3. REAR VIEW, URM PUBLIC SCHOOL
PUGET SOUND REGION

FIGURE 5-4. URM PUBLIC BUILDING
CALIFORNIA COAST REGION

middle levels. The granite-clad walls at the lower level are 27 inches (0.7 m) thick. The stone exterior is coursed with the brick backup wythes. The gable ends above the upper level were originally brick faced with sandstone. Some of these gable ends collapsed in an earthquake with an intensity of about 0.2 g EPA. For this analysis, the original construction will be assumed. The walls are not anchored to the roof or ceiling construction. The concrete floors are cast over the interior brick wythes but the metal lath floor reinforcement barely extends into the interior wythe of brick.

This representative building has survived, but with the described damage, an earthquake of approximately 0.2 g EPA. It will be analyzed for its siting within a seismic zone of 0.4 g EPA.

5.5 APARTMENT AND HOTEL BUILDINGS

Representative URM apartments include the single rectangular structures shown in Figure 5-5. Larger apartment buildings are constructed in wings to allow light and ventilation to interior rooms (Fig. 5-6). Hotels such as that shown in Figure 5-7 are larger but similar in configuration to large apartment buildings. The single exception is that the first floor is generally commercial space and comprised of large open areas. The apartment buildings shown represent a large number of the existing URM buildings, and each will be analyzed in this study.

Composite buildings similar in size and height to those shown in Figures 5-5 and 5-6 will be assumed, with average sizes as shown in Table 4-5. The representative buildings will utilize wood roof and floor framing. A non-structural brick veneer will be assumed on the URM wall at the street front of both buildings. Existing anchors at a spacing of 6 ft (1.8 m) to joists and rafters will be assumed.

The moderate size apartment building (Fig. 5-5) will be considered as sited in seismic zones of EPA of 0.2 g and 0.4 g. The larger building (Fig. 5-6) will be studied in the seismic zone of 0.4 g only.

FIGURE 5-5. REPRESENTATIVE URM APARTMENT BUILDING OF MODERATE SIZE

FIGURE 5-6. REPRESENTATIVE URM APARTMENT BUILDING OF MODERATE TO LARGE SIZE

FIGURE 5-7. URM HOTEL, CALIFORNIA COAST REGION

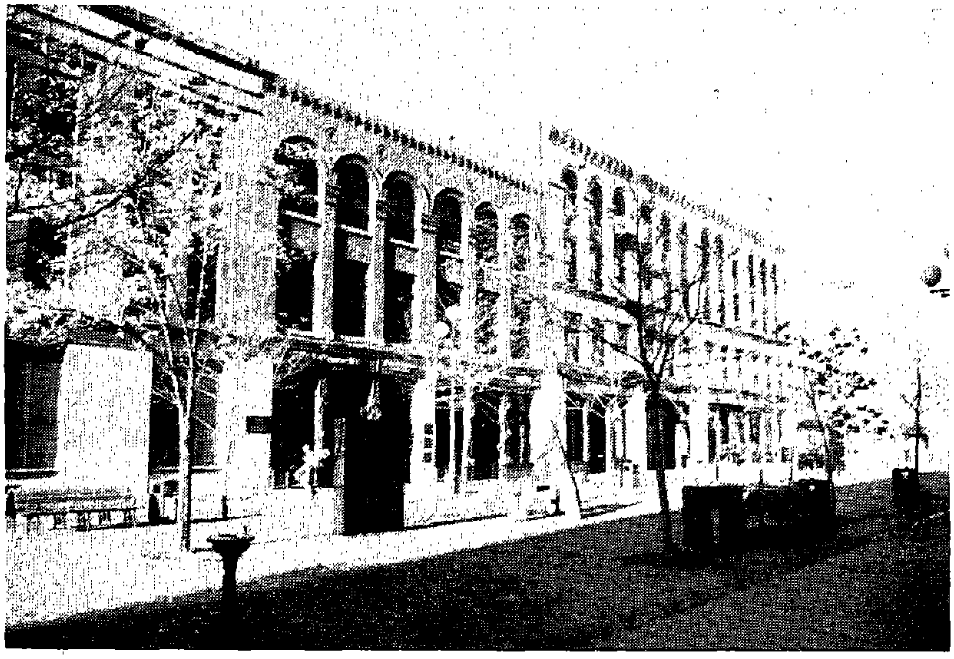

FIGURE 5-8. URM COMMERCIAL BUILDING
PUGET SOUND REGION

5.6 COMMERCIAL AND OFFICE BUILDINGS

This class of URM buildings has a great diversity of characteristics, as shown in Table 4-5. The representative building selected for study is similar to that in Figure 5-8. This three-story building, about 60 by 150 ft (18 by 46 m) in plan dimensions, on an interior commercial lot, represents possibly 70 to 80 percent of the total of this class of occupancy. The roof framing is of wood sheathed with straight boards, and the floors are wood with double wood sheathing, one layer laid diagonally, the other a finish wood flooring. A steel lintel beam on steel or cast iron columns supports the URM street-front facade. Use of wall anchors at non-bearing walls is infrequent and spacing on bearing walls averages 8 ft (2.4 m).

The floors above the nearly open first floor have wood stud partitions extending floor to floor. The partitions are closely spaced and the floors and walls are interconnected by finish materials. This building is considered to be sited in a seismic zone of 0.2 g EPA. The performance of the open street front in a seismic zone of 0.4 g EPA will also be considered.

5.7 CHURCHES

This group of buildings have a uniqueness that makes selection of a representative building difficult. Accordingly, the analyses of the other occupancies that have similar characteristics will be applied to parts of these structures.

5.8 POST-1950 INDUSTRIAL BUILDINGS

A composite of this class of buildings will be analyzed to determine seismic performance and determine probable life-safety hazards. The building will be comprised of a single-story space, 150 by 200 ft (46 by 61 m) in plan, with 20 ft (6 m) clear height under the roof framing. A two-story office space of 60 by 150 ft (18 by 46 m) will extend along the street frontage. Exterior walls and a separation wall of unreinforced concrete masonry units similar to that shown in Figure 5-9 will enclose the office space. The office portion will be nearly open on the

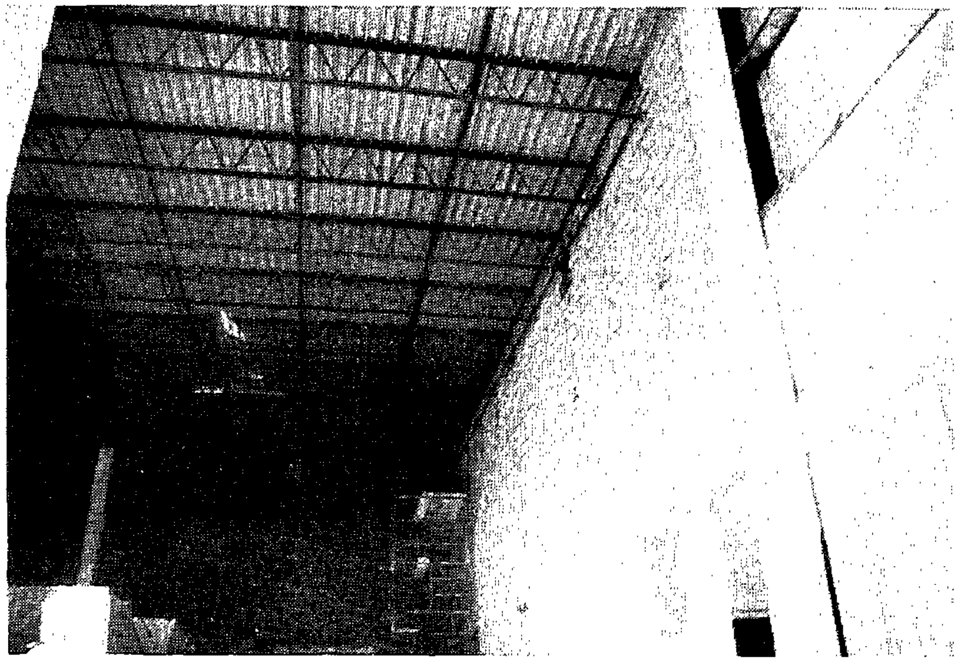

FIGURE 5-9. COMMON CONSTRUCTION MATERIALS, POST-1950 URM BUILDING

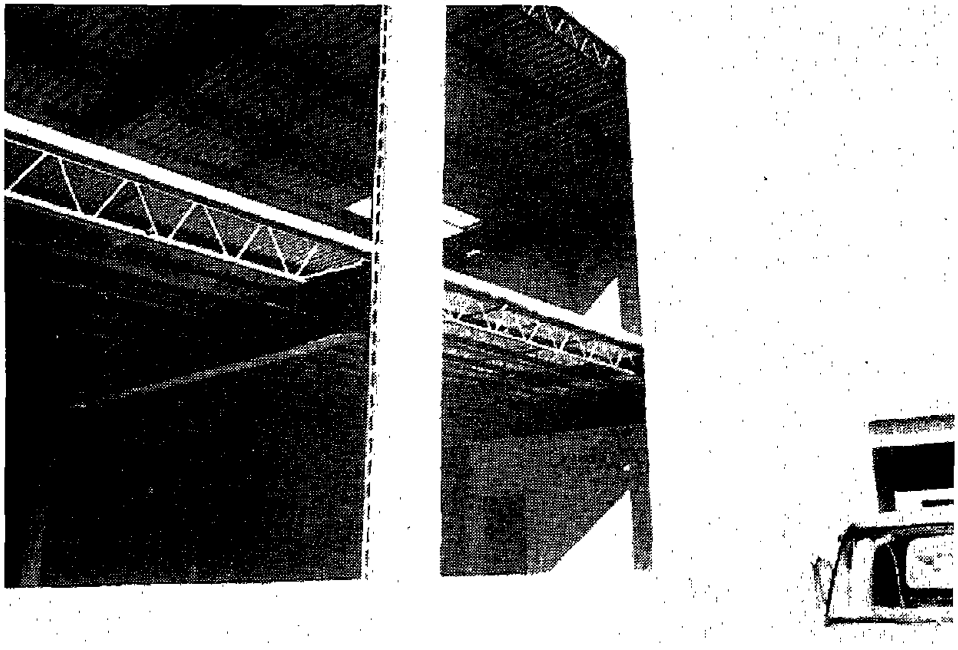

FIGURE 5-10. COMMON CONSTRUCTION MATERIALS, POST-1950 URM BUILDING

street front, similar to the configuration shown in Figure 5-10. Roof and floor framing is steel decking supported by steel joists and an interior steel frame. Interconnection of the exterior walls and the horizontal floor and roof elements is not designed.

For the purpose of this analysis, the building will be considered to be in a seismic zone of 0.1 g EPA.

5.9 POST-1950 COMMERCIAL BUILDINGS

These recent URM buildings are similar to the moderate size pre-1940 commercial buildings, except for the materials used for floor and roof framing. Steel framing and steel decking, concrete filled at the floors, are common for post-1950 buildings. A nearly complete interior steel frame supports the majority of vertical loads. Because the selected post-1950 industrial building has similar construction and size characteristics, its analysis will serve as representative of both commercial and industrial buildings.

SECTION 6

CONCLUSIONS OF THE CATEGORIZATION STUDIES

6.1 USABILITY OF FIELD PROCEDURES

The information sources used in the field survey were adequate for this generalized categorization study. However, existing construction is given little attention by the majority of the construction-related and construction industry. Therefore, the interviews of current personnel of architectural and engineering offices, building officials, and construction companies could have been supplemented with interviews of retired professionals and supervisory construction personnel.

The time spent in the field survey could have been more efficiently used if the following procedures were followed. A personal street-by-street walking survey by the researcher is necessary to provide a background for planning of local interviews. An interview format keyed to the significant buildings observed in the walking survey should be prepared and a specific list of interviewees for each significant category should be prepared. The interviewer must ask pertinent questions to obtain in-depth information. The information should be recorded in the format outline. If several investigators are being used, common forms and notations are an absolute necessity, as reduction and review of the survey information by other researchers is dependent on the use of uniform methods for gathering and recording information.

6.2 PROBABLE RANGE OF INFORMATION GATHERED IN SURVEY

In the planning of this categorization study, two trips to each of the selected geographic regions were scheduled. The first survey visit was limited in time (KKA, 1978), but was planned to survey known significant categories of URM buildings in that region. A general survey of the entire area was made in addition to the specific survey. The interviews obtained information about unique or historical structures that incorporated regional construction characteristics. The second visit expanded the information gathering related to special classes of URM buildings and scheduled survey time to explore the diversity of URM construction. The full range of available information in any region probably exceeds the capacity of the surveyors to absorb information. A period of sorting and reviewing data to note lack of information about pertinent materials and construction methods and to add interviewees that may have specific historical knowledge, is very desirable. By use of this technique the full range of the characteristics of URM buildings was obtained.

6.3 ACHIEVEMENT OF OBJECTIVES

This categorization study utilized the planning and techniques previously discussed. Prior to beginning the survey, the researchers were aware of general identifiers for buildings that will influence structural response to moderate and strong intensity of ground motions. The full technique of information gathering became apparent after the first regional surveys. The regional surveys were not completed consecutively; therefore, time was available to review techniques and objectives.

The objectives of the categorization study were attained. The descriptors for significant categories of URM buildings in the United States were simpler and more straightforward than was originally anticipated. Regional surveys subsequent to the early visits were much more efficient in gathering pertinent data.

6.4 GENERAL APPLICATION OF CATEGORIZATION STUDIES

These categorization studies were not intended to be a data-gathering project for implementation of a mandatory earthquake hazard mitigation program. They are a useful guideline for preliminary planning of an earthquake hazard mitigation program. Specific numbers of buildings were not obtained in the survey. Categories of buildings that can be developed into hazard rankings were developed. The commonality of each category can be determined and the commonality of earthquake hazard posed by that class in a specific seismic zone can be reasonably determined. From this data base, planning of earthquake hazard mitigation programs can be initiated. When specific numbers of structures are obtained by special surveys, building by building, the numbers can be combined with general earthquake hazard mitigation cost data. These cost data would be estimated from analyses and recommended retrofits prepared for the categorized buildings.

6.5 RECOMMENDATIONS FOR FURTHER STUDY

This categorization study is a part of a multi-faceted research program to develop a methodology for mitigation of seismic hazards in existing unreinforced masonry buildings. The research program is intended to be nationwide in scope and be primarily a technical document for determination and mitigation of hazards. Use of the developed methodology for determination of earthquake hazards in an existing inventory of URM buildings in an urban area, coupled with an area-specific survey, can develop guidelines for developing economic data. These guidelines for developing economic data, when combined with guidelines for social studies to determine the impact of hazard mitigation programs. can be utilized by governmental entities to determine the cost-effectiveness of earthquake hazard mitigation programs.

A definitive study encompassing all of these elements in a special study zone would be a valuable resource for development of local and regional earthquake hazard mitigation programs.

SECTION 7

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