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Seismic Design Decision Analysis
Report No. 28

COSTS OF REINFORCING EXISTING BUILDINGS AND CONSTRUCTING NEW BUILDINGS TO MEET EARTHQUAKE CODES

by

RICHARD D. LARRABEE
ROBERT V. WHITMAN

May 1976

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Methods of reinforcing existing buildings are discussed. Estimated costs for reinforcing 156 buildings are presented. Reinforcing costs are on the order of $5 to $18 per square foot for masonry bearing wall buildings. Costs are lower for other structural types or buildings with previous seismic design. Costs are higher for older buildings, smaller buildings and historic buildings. The percentage of older existing buildings is estimated; an examination of U.S. codes illustrates how few existing buildings were designed for seismic load.

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ABSTRACT

The costs of constructing new buildings to seismic codes are reviewed. A particular building, designed with and without seismic load is examined; design for seismic load increased with total cost 2.8 percent. Under more general circumstances, cost increases would be one percent or less. Some impacts of the implementation of a new seismic code are discussed.

Methods of reinforcing existing buildings are discussed. Estimated costs for reinforcing 156 buildings are presented. Reinforcing costs are on the order of $5 to $18 per square foot for masonry bearing wall buildings. Costs are lower for other structural types or buildings with previous seismic design. Costs are higher for older buildings, smaller buildings and historic buildings. The percentage of older existing buildings is estimated; an examination of U.S. codes illustrates how few existing buildings were designed for seismic load.

PREFACE

This is the twenty-eighth in a series of reports covering research supported by the National Science Foundation under grant GI-27955, as part of the program for Research Applied to National Needs (RANN). A list of previous reports appears at the end of this report.

This report is identical with a thesis written by Richard D. Larrabee, Research Assistant, in partial fulfillment for the degree of Master of Science. The thesis was supervised by Robert V. Whitman, Professor of Civil Engineering.

We are indebted to many individuals who generously provided information used in this report. Three who contributed the majority of the material are Mr. Ronald Jackson, Chief Structural Engineer, CE Maguire, Waltham, Massachusetts; Mr. William A. Lamb, Chief Structural Engineer, School Building Planning Division, Los Angeles City Unified School District; and Mr. James Lefter, Director, Civil Engineering Service, Office of Construction, Veterans Administration, Washington, D.C.

We also appreciate information provided by Mr. Charles Curtis, Structural Engineer, Long Beach, California; Mr. Robert Elder, Cabot, Cabot and Forbes, Boston, Massachusetts; Mr. Paul Folkins, City of Boston Building Department; Dr. Frank J. Heger, Consulting Engineer, Cambridge, Massachusetts; Mr. Warner Howe, Gardner and Howe, Memphis, Tennessee; Mr. Herbert Isenberg, Architect, Boston, Massachusetts; Mr. Arthur Poulos, Massachusetts Bureau of Building Construction; Dr. James Radziminski, University of South Carolina; Dr. Norton Remmer, Massachusetts State Building Code Commission; and Mr. Emil Wang, John Blume Associates, San Francisco.

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INTRODUCTION

A policy decision about earthquake safety necessarily involves a balancing of the risks of earthquake damage and disaster with the costs of protective measures. For the foreseeable future the main protection against earthquakes will be the adequate construction of buildings and other facilities to resist earthquake forces. Earthquake resistant construction is a proven safety measure but it is not a costless solution. This thesis examines the costs of providing earthquake resistance in buildings to better define one side of the earthquake safety issue.

The problem divides itself into two parts. The first is the cost of constructing new buildings for higher earthquake forces and standards. Currently available cost estimates are examined in the context of the process of building design and code implementation. The second part is the cost of reinforcing existing buildings for higher earthquake forces and standards. Techniques and experiences with reinforcing are discussed; costs are estimated by examining data on actual and proposed building reinforcement projects.

CHAPTER 1

COST OF EARTHQUAKE RESISTANT NEW CONSTRUCTION

REVIEW OF REDESIGN COST ESTIMATES

Two studies were completed in 1974 which estimate the premium paid for constructing a new building to a more stringent earthquake building code. In these studies selected "typical" buildings, originally designed for one level of earthquake resistance, were redesigned to a higher level. The cost of the changes in the building following the redesign were estimated and expressed as a percentage increase in the total cost of the building.

The M.I.T. study (Whitman, et al., 1974) examined the cost increases for high rise, slab shape apartment buildings (originally designed for wind only) which were redesigned to various levels of the Uniform Building Code (UBC) earthquake provisions. A change from no earthquake design (zone 0) to UBC zone 3 cost 2 to 3% for the steel frame buildings with braced bays and 4 to 5% for the concrete frame and shear wall buildings. About one whole percentage point can be attributed to the requirements (used in the study) that all masonry infill walls be reinforced. Ductility requirements for concrete members contributed to the higher cost of the concrete buildings.

One other building was studied, a 13 story, steel frame office building. Its total cost increase from zone 0 to zone 3 was about 4.5 percent, much higher than the apartment building of comparable height. This greater cost can be attributed to the lack of any braced walls and the taller story heights and longer spans in the moment-resisting frames.

A similar comparison was done for a variety of buildings in the ATC-2 study (Applied Technology Council, 1974). Eleven buildings already designed to the 1973 UBC zone 3 code were redesigned using a spectral analysis method which had a base shear about twice the zone 3 force. Again the cost increase varied with construction system. Seven of the buildings had a cost increase of 2% or less. Two concrete buildings which had a problem resisting the overturning moments at the foundation level had a cost increase of 3 to 4 percent. Two low rise buildings with floor and roof diaphrams lacking excess strength required extensive design modifications resulting in cost increases of 8 and 9 percent.

CASE STUDY: THE REDESIGN OF BUILDING 'B' FOR EARTHQUAKE LOAD

To make an incremental contribution to the literature on the costs of redesigning for earthquake, this section presents a case study of a real building which was designed first for no seismic load and then for UBC zone 2 requirements.

The building, a combined library, lecture hall, cafeteria and classroom building for a school, is illustrated in Figure 1. Completed in 1976, it is a steel framed structure designed for the seismic requirements of 1967 UBC zone 2. However, prior to 1970, the building was planned to be a concrete, flat plate structure with no earthquake design. Figure 2 is an architectural rendering of this original building. Between the completion of the preliminary design shown in Figure 2 and the beginning of working drawings for construction, the municipality in which the building is located added the earthquake design requirements.

Figure 1: Building 'B' as Completed in 1976

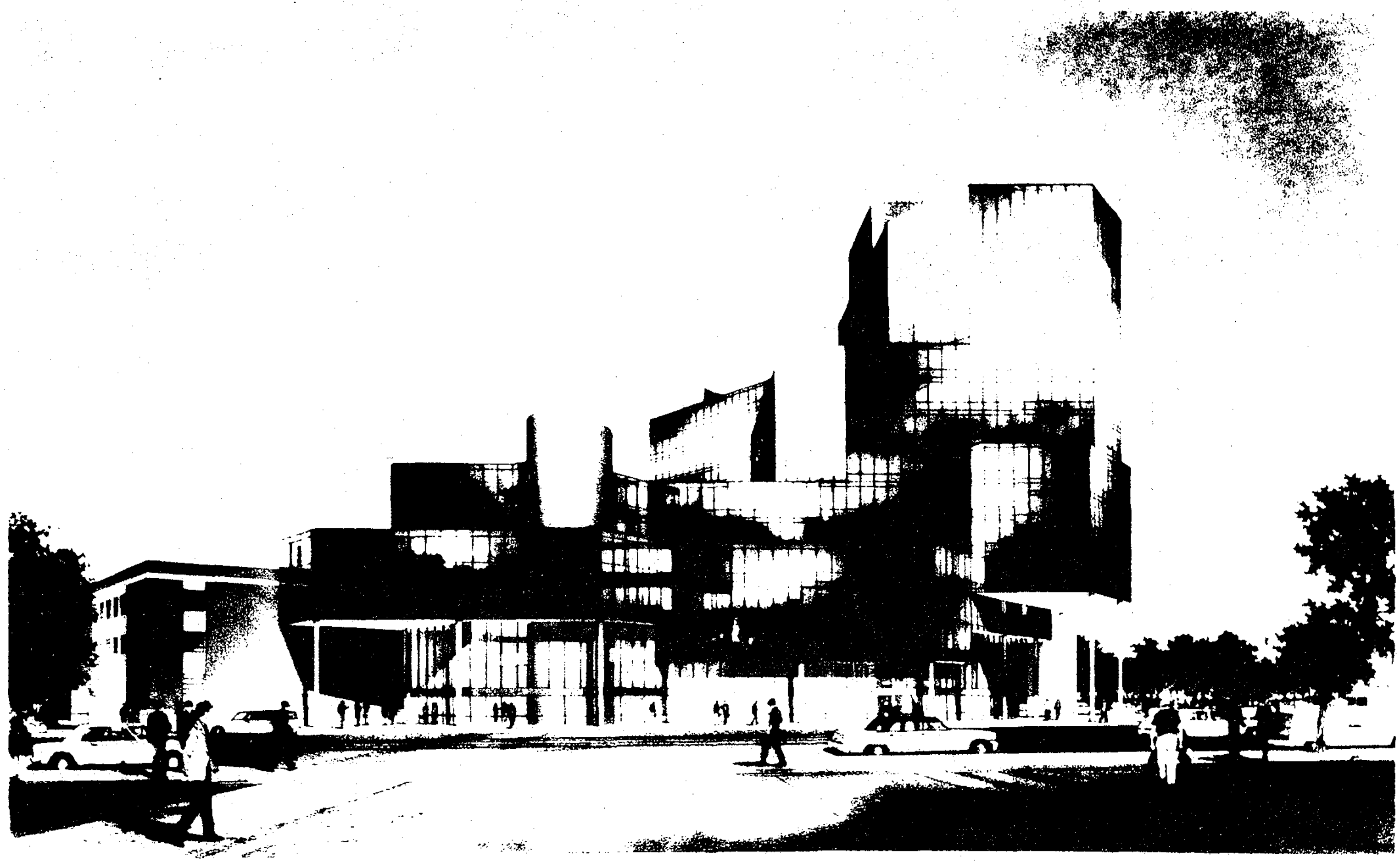

Figure 2: Building 'B,' Preliminary Rendering of Pre-Earthquake, Concrete Design, Prior to 1970

Design for Earthquake Load

The designers of the building, CE Maguire, Inc., Waltham, Massachusetts, checked the original design to make sure it would comply with the new regulation. It was found that the flat plate and column structure could not be made to resist the moments and shears that would have been developed by the zone 2 design loads. An underlying principle of this analysis was the Portland Cement Association recommendation that until more research has been done on the seismic performance of flat plate construction, the effective beam should be no wider than the width of the column and twice for slab thickness (Blume, et al., 1961). For a 10" floor slab this narrow width proved to be inadequate for strength.

The building was also analyzed as a shear wall building. One position for shear walls was the solid walls next to the elevator core and stair wells shown in Figure 3. However, these elements alone were too narrow to resist overturning and were so far apart that the slab thickness would have to be increased to carry the loads to the shear walls.

Several ideas were suggested for modifying the building so that a concrete system could be retained. One of the reasons that the earthquake load presented a problem was that the building was so unsymmetric; torsion was introduced by the variation of centers of mass of each floor.

A complete new layout of the building on a symmetric plan or the addition of numerous shear walls would have made a flat plate system viable. These changes were considered but the project was too far along in the design process to change the entire building to another shape.+

+The odd shape was not arbitrary: the site itself was irregular, a single taller tower was undesirable for school purposes and different uses required different floor areas.

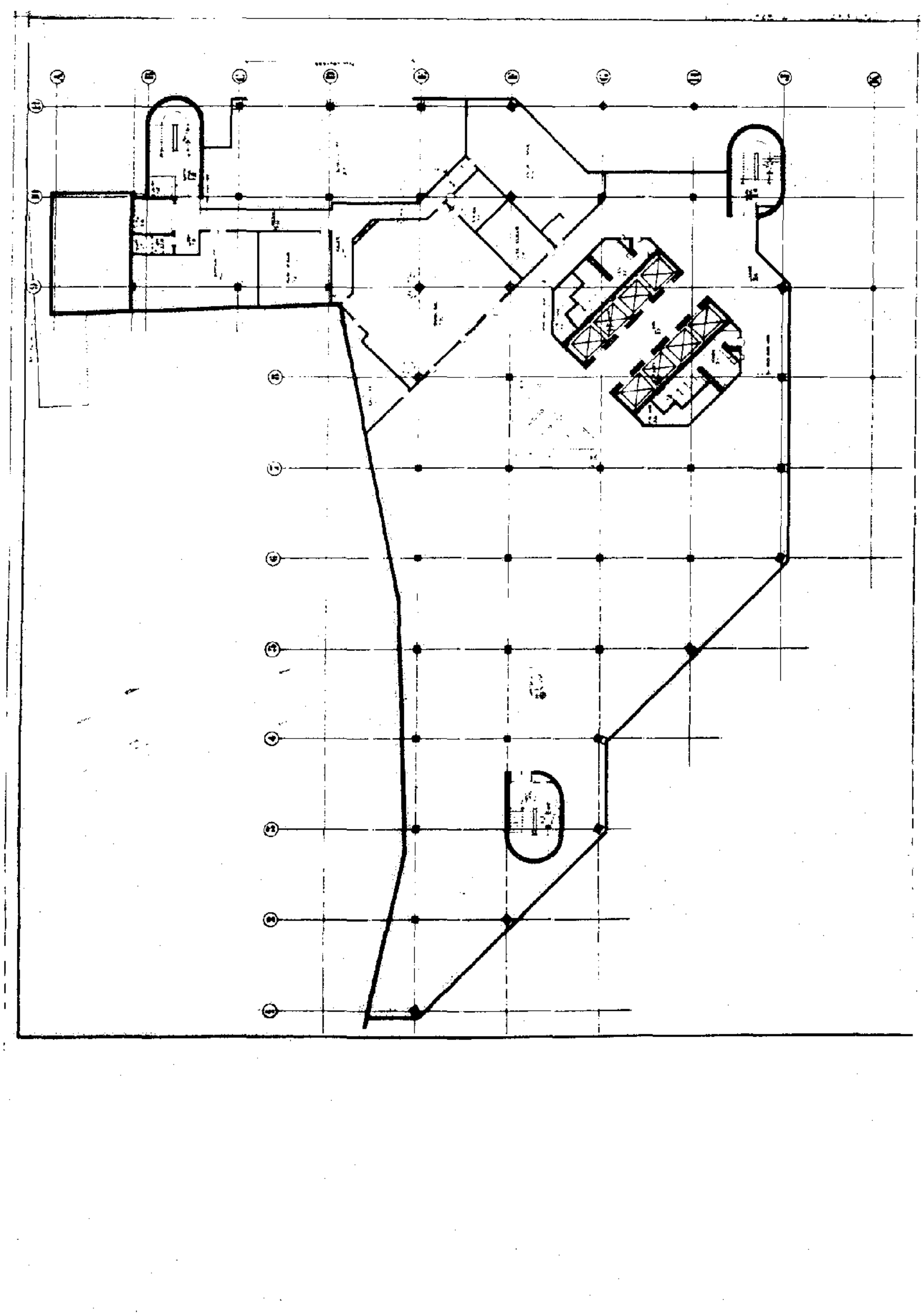

Figure 3: Building 'B,' Third Floor Plan

Further, numerous shear walls were objectionable because one of the purposes of this building was to provide flexible space for library expansion.

The resolution of the problem was to change the structural system to a true moment resisting frame. A moment-resisting, concrete frame was considered but rejected because the 30 inch deep beams were too deep. Finally, a concrete waffle slab system and a steel frame system were considered, both of which qualify as a moment-resisting frame. Although the prices were comparable, the concrete waffle slab required complicated reinforcing arrangements. Structural steel provided full ductility without unusually expensive or difficult connections and so was selected.

The Cost of Earthquake Requirements

Estimating the Cost Increase. How much cost was added to the building by the changes necessitated by the earthquake design requirements could be determined by comparing the bid price for the original concrete building and the bid price for the steel frame building. Unfortunately, no bids were received on the original buildings, so some comparison with the engineer's estimate is necessary. Because there were no changes in the masonry partitions, exterior facade or ceiling system from the original concrete building to the final steel building, it is reasonable to compare the structural costs alone.

Mr. Ronald Jackson of CE Maguire, Inc., has provided a comparison of the cost of the steel building that was built and the original concrete design. This information is summarized in Table 1. The contractors bid

Table 1: Cost Comparison of Building 'B' Before and After Earthquake Design

1. Final Building, steel, with earthquake design (prices from contractor's bid, Feb. 1973 construction start)

Structural Items:

structural steel materials	$1,000,000	
structural steel erection	800,000	
reinforcing steel	181,000	
foundation concrete and forms	192,000	
metal deck	710,000	
superstructure concrete	305,000	
superstructure forms	470,000	
fire proofing	58,000	
foundation piles	585,000	
Structural total		$ 4,301,000
Entire building total		$14,300,000

2. Original Building, concrete, without earthquake design (prices from engineer's estimate escalated to a Feb. 1973 construction start)

Structural Items

superstructure	$2,842,000	
basement level	113,000	
pile caps	125,000	
foundation piles	832,000	
Structural total		$3,913,000

3. Difference in cost - $388,000

Percentage of total building cost

$$= \frac{388{,}000 \times 100}{(14{,}301{,}000 - 388{,}000)} = 2.8\%.$$

for the entire building was $14.3 million of which $4.3 million was for the structural items listed in Table 1. To arrive at the cost of the equivalent structural items of the original concrete building, it was necessary to modify the original preliminary estimate prepared by the engineer in 1970. Adjustments included escalating prices to the construction start, adding the cost of more piles for the heavier concrete building, and adjusting for other differences in the basement construction. The adjusted structural cost of the original building was $3.9 million, $388,000 less than the steel building with earthquake design. The earthquake requirements added 2.8 percent to the total cost of this building.

Comparison with Other Estimates. This cost increase of 2.8% is much higher than any of the prototype studies would indicate for a change from zone 0 to zone 2 criteria. The MIT study (Whitman, et al., 1974) found that the 11 story concrete apartment building increased in cost by 2.5 percent from zone 0 to zone 2. One percent of the 2.5 percent was for reinforcing non-structural masonry walls (a requirement not in the code for Building 'B') so the comparable percentage increase is 1.5 percent. While one would expect that an advantageous change in structural systems would have restrained the cost increase, the increase was almost double that of a building which remained concrete.

This high cost can be partially explained by two considerations. First, the building has an unsymmetric profile in both plan and elevation. The torsion induced by the eccentric loading resulted in member forces higher than for a rectangular building.

Second, the method of strenghtening the apartment building was based on the addition of shear walls. This is a much more efficient way to resist lateral forces than with a large span, moment-resisting frame. The economy which might have been anticipated in switching structural systems was more than compensated for by the larger costs associated with a non-symmetric, non-braced building.

Other Consequences of Earthquake Requirements

Besides the change in cost, the earthquake provision resulted in some other changes in the building. The original scheme had tall concrete columns with no bracing between them, along the entrance side of the building (see Figure 2). The concrete appearance remained by covering the steel columns with concrete but it was necessary to add some extra bracing between the columns which changed the architectural effect somewhat from the original idea.

Also in switching to an all steel system, some of the natural advantages of concrete for the original plan were lost. The diagonal placement of the central elevator core and the varying and odd sized bays required more difficult framing in steel but were not a problem for a continuous system like concrete.

Not to be neglected are the design costs. Since this was the first building CE Maguire had done which had to conform to a strict seismic code, they spent some additional time in analysis. They feel that now they would know how much attention should be given to various seismic requirements in the planning stage so that all the design disciplines would be able to accomodate structural needs. The implication is that the learning time from the start of a new code is one difficult project.

FACTORS TO CONSIDER IN EARTHQUAKE COST ESTIMATES

There are limits to the economies which can be achieved simply by changing the structural system. In fact, Building 'B' has shown that changes in the structural system may be the least efficient of all ways to lower the cost of earthquake design. In a more typical design situation, the seismic loads are considered at the beginning or at least at a time before the designer is constrained by a rigidly fixed architecture. Modifications in the architecture can lead to more economical earthquake design.

The Design Process

We can identify three stages in the evolution of the design of buildings after the introduction of earthquake design requirements. In stage one, earthquake loads are added on to some already conceived building; the added costs are the highest. In stage two, the plan of the building is changed to reduce the loads and accomodate a better lateral force resisting system; the added costs are lowered. In stage three, improvements are made in lateral force resisting systems and the architecture modified so that a minimum amount of material is needed above the amount required for gravity loads.

Interpreting Redesign Estimates

Building 'B' is a better example of stage one than the redesign studies. The much higher costs for Building 'B' can be attributed to its lack of the simplicity of the other buildings studied. The ATC-2 report clearly states that all the real buildings selected for redesign had regular plans and a clearly defined lateral force resisting system.

The buildings in the MIT study had a clear lateral force system: moment resisting exterior frames in the long direction, exterior shear walls or braced frames in the short direction, and positions on the interior for shear walls between apartments. The selection of the prototype zone 0 building anticipated the larger loads that would have to be resisted. Thus important earthquake design provisions were already in the building before it was designed for higher loads.

These architectural changes for better seismic resistance can be considered to have been achieved at zero dollar cost. The estimates of the redesigned buildings, exclusive of building 'B,' are then fair estimates of the costs at stage two of the evolution of earthquake design.

Lower Costs with Architectural Changes

Present Evidence. There is clear evidence that the costs of earthquake design are being kept low through the combinations of a judiciously selected structure and plan. John Blume of John A. Blume and Associates, Engineers supports this assertion: "The additional cost is often not very great, sometimes, practically nothing, providing and only providing, the engineer takes an active part in the basic layout of the structure" (Blume, 1970).

James Lefter, of the Office of Construction, Veterans Administration, has cited a building constructed to meet a lateral force double the UBC zone 3 force. After the building was finished, he identified all the items of cost which could possibly be attributed to the higher design requirements (above the 1973 UBC zone 3 requirements). This amounted to $1 million, which is less than 2% at the cost of this $55 million building. This low cost was achieved through a clear understanding between the engineer and architect that the plan was to be symmetric and provisions were to be made from the beginning for shear walls.

Future Earthquake Costs and the Evolution of Tall Building Design. We have suggested that some time after the introduction of seismic codes building design will be in the stage three situation. Reaching this objective depends on the evolution of structural and architectural systems together. Exactly what savings and changes in the architecture will occur (and how soon) would be difficult to predict because it depends on the ingenuity of the designers.

However, a similar process has taken place in the evolution of tall building design. Traditionally, office buildings are built with a moment-resisting frame with columns on a regular gird; braced bays are added for taller structures. This system produces minimal interference with the architecture: there are large column free spaces, broad options for the treatment of windows and facade between widely spaced columns, and the bracing is usually hidden in the elevator core.

The conceptual revolution in tall building design was, of course, the tube building or external shear wall building. A more efficient structural system is substituted for a less efficient system and a substantial savings is realized. The Hancock and Standard Oil of Indiana buildings in Chicago have an average structural steel weight of

31 and 33 pounds per square foot of building area. This is a weight comparable to a conventionally framed 30 to 60 story building (Picardi, 1973). No premium was paid for the extra 40 to 70 stories.

There are some architectural limitations with the tube system: the lower stories cannot be "opened up" and the windows are limited in dimensions. Other features can be used to architectural advantage. Altogether, it would be difficult to attribute any shortcomings of these buildings to this marriage of architecture and structure.

It is structurally possible to resist significantly greater lateral loads at almost no extra cost and with acceptable changes in the architecture. Earthquake design, of course, requires more than just higher loads, but it is conceivable that seismic design could be achieved at a very low cost and with modifications in building architecture no more radical than the evolution of the architecture of tall buildings.

CONCLUSION

This chapter has tried to show that if the seismic design is achieved through the proper selection of both structure and building configuration, then the cost premium is minimized. The penalty of an irregular plan and lack of lateral force resisting elements is evident in the Building 'B' case. Designers will quickly move into the stage two design situation and build regular buildings which will have seismic cost premiums on the order of those in the MIT and ATC-2 studies. In a much longer period of time, earthquake design will evolve in some manner similar to wind design so that the cost premium will diminish further.

CHAPTER 2

REINFORCING EXISTING BUILDINGS FOR EARTHQUAKE LOADS

As suggested in the last chapter, the cost of constructing new buildings to even very stringent requirements can be kept to a low amount. Chapter 4 will show that this level is probably not a significant factor in the overall cost of a building. For any building constructed in the future, seismic safety can be achieved at tolerable costs if so desired.

Seismic design for new construction solves part of the problem; many existing buildings have not been designed for earthquake loads. Chapter 4 will discuss the scope of the existing building problem. This chapter discusses some of the methods that have been used to reinforce existing buildings and some of the experiences of the organizations which have pursued reinforcing policies.

METHODS OF REINFORCEMENT

Methods of reinforcement vary with the conditions of the existing building but always include the following:

1) assuring that the floors and roof of the building can act as a diaphram to distribute the lateral forces to the lateral force resisting system; and
2) providing a lateral force resisting system strong enough to resist the developed forces.

Buildings with wood floors and roofs or with light metal deck roofs often cannot develop the necessary diaphram forces and must be reinforced.

Concrete floors usually have enough strength to resist the diaphram forces and are adequately tied to the lateral force resisting system when the floors are cast in place.

What lateral force resisting system is created depends on what elements of the original building can be included in the new lateral force resisting system. In concrete frame buildings, the frames are made strong enough to resist lateral forces by the addition of reinforced masonry or concrete in some or all of the bays. This is often the best solution if the building is already stiff structure due to non-structural masonry infill (Lefter, 1975). The concrete frame becomes a boundary element for the new panel.

Masonry Bearing Wall Buildings

The most problematical type of building to reinforce is the masonry bearing wall building. It is heavy and so collects higher loads but has little reserve strength. Also, there are few elements in the building which can be easily modified to become a lateral force resisting system.

Figure 4 illustrates a proposed strengthening method for such a building. Two varieties of new shear walls were added: reinforced block masonry and stud walls sheathed with plywood. In this building shear walls needed to be added at intermediate points because the floors were not strong enough to transfer all the forces to the side walls. The floors are stiffened with new blocking between the joists and new plywood flooring. The floors are tied to the new and existing walls by grouting the joist pockets and bolting the wood blocking to the wall as illustrated in details 7 and 8 of Figure 4. The roof is braced and also tied to the

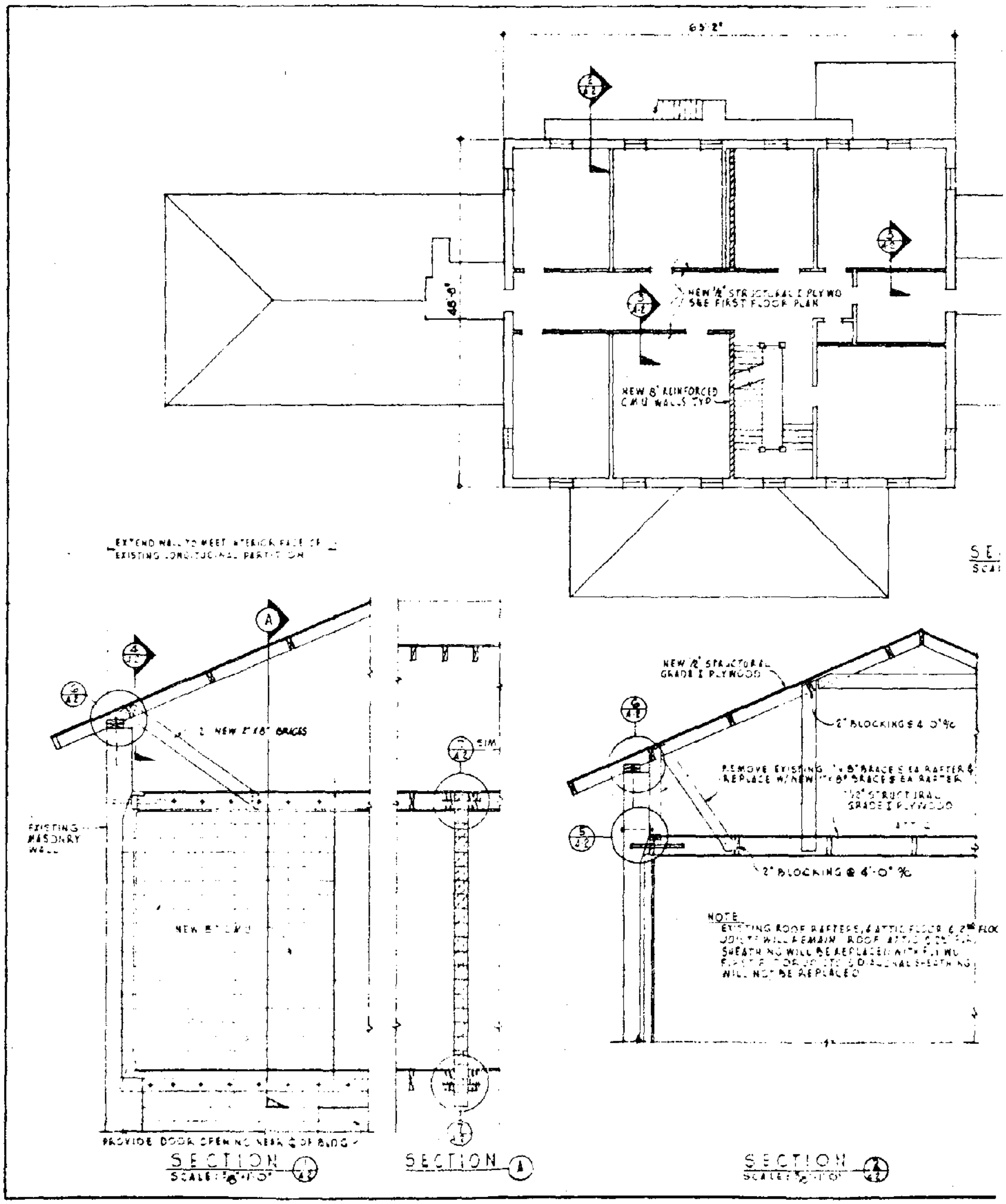

Figure 4: Earthquake Reinforcing for a Masonry Bearing Wall Building with Wood Floors

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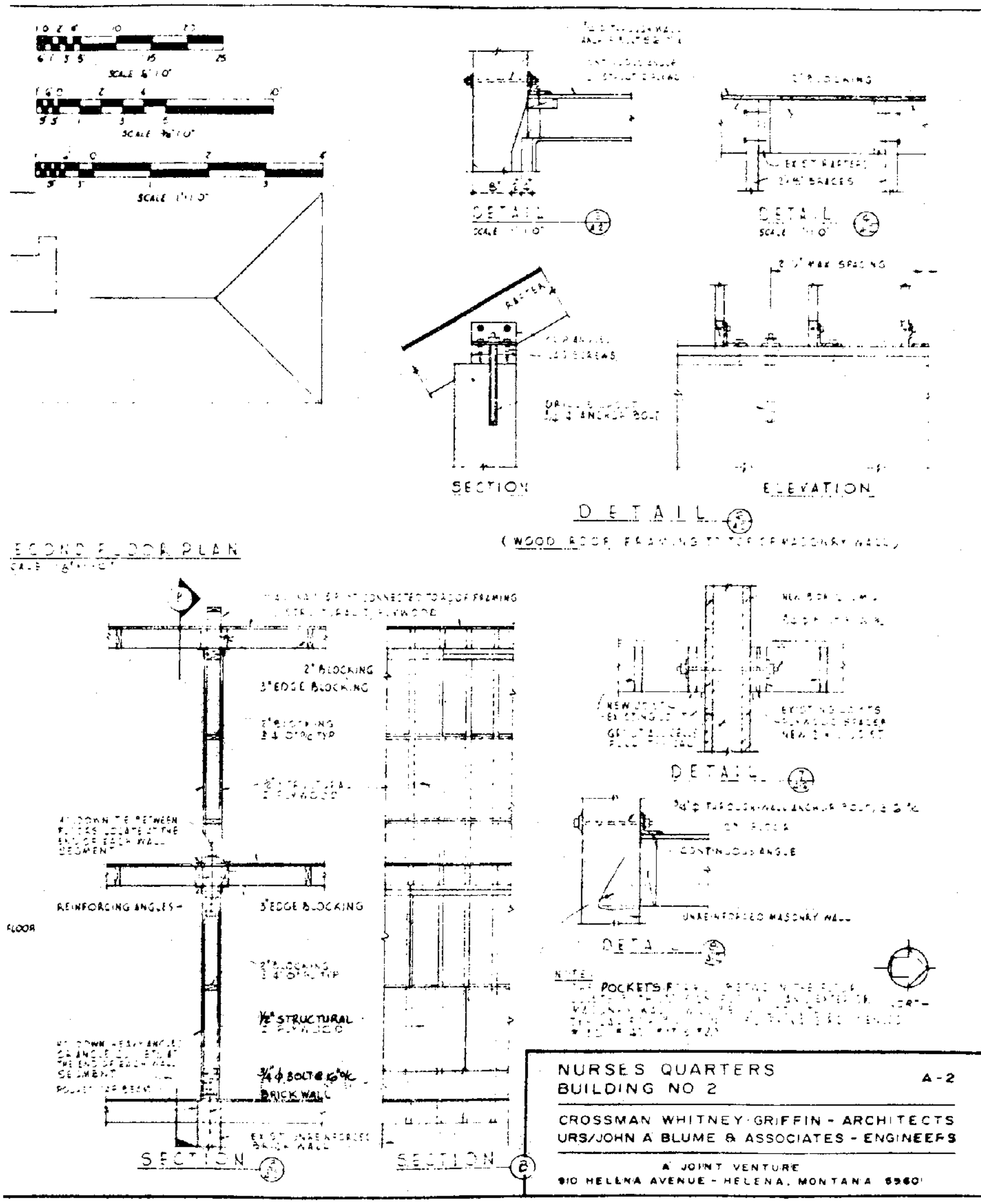

Figure 4: (cont.)

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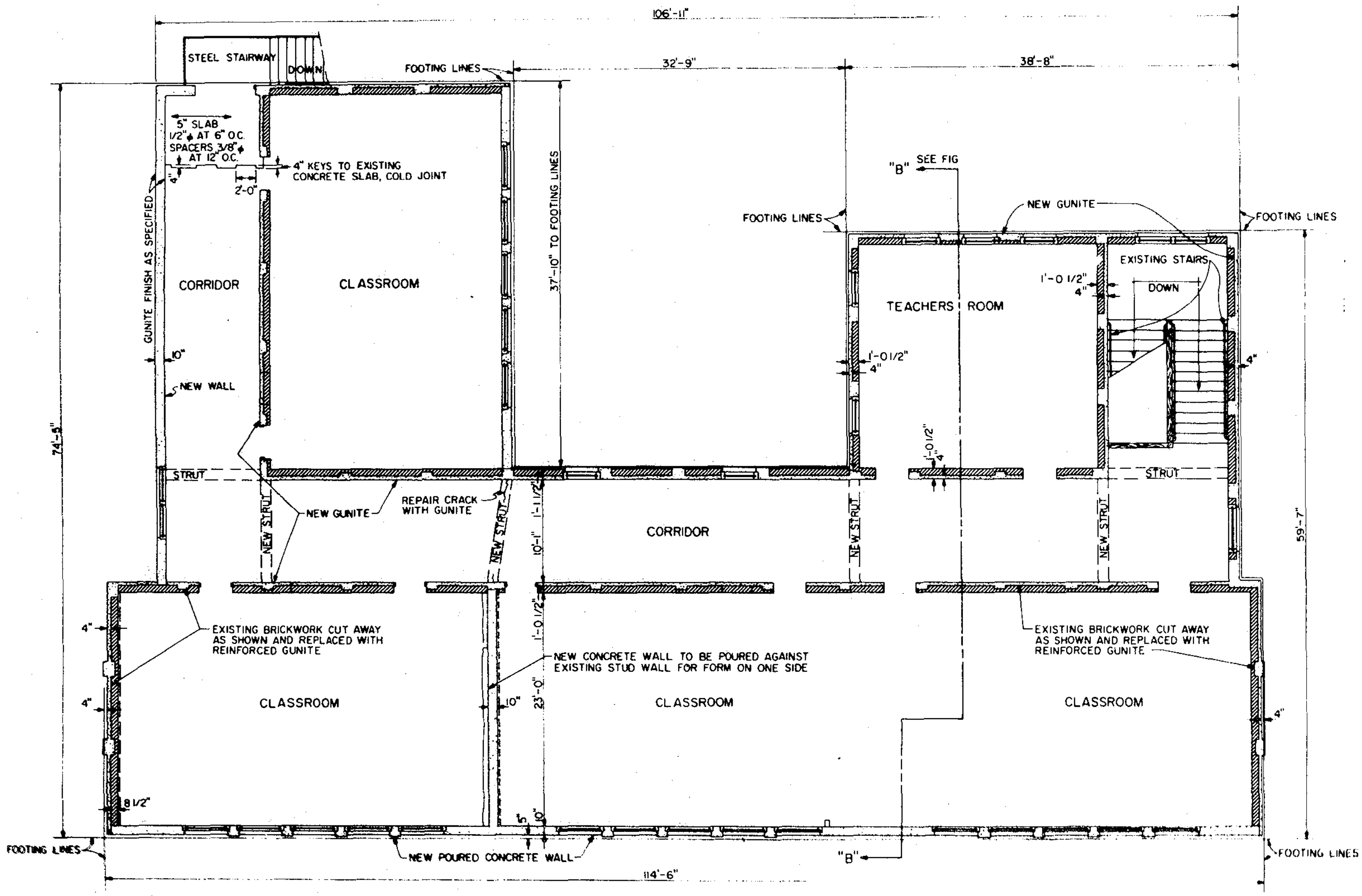
new walls and original exterior walls.

If this building had sufficient floor and roof diaphram strength, then the shear walls would not be needed for reducing the floor spans but only to relieve the load on the original exterior masonry walls. As an alternative to adding new shear walls, the original walls can be strengthened. There are several methods of doing this as the next example. illustrates.

Reinforcing for a School Building. The South Building of the San Fernando Elementary School was originally constructed in the mid-1920's and was reinforced for earthquakes in 1934 under the provisions of the Field Act (Jephcott, et al., 1974). The building, illustrated in Figure 5, is a two story, masonry bearing wall building with wood floors and roof. Although the reinforcing work was done many years ago, the building is similar to the school buildings for which the costs are examined in Chapter 3.

Figure 5a shows that at least two methods were used to strengthen the exterior walls--either the wall was replaced completely with a reinforced concrete wall or the wall was covered with a layer of reinforced gunite (pneumatically applied concrete). A new interior concrete wall was added also. Unlike the building in Figure 4, this building was reinforced under the provisions of the predecessor of Title 21, the regulations for school house construction in California. These regulations require that all reinforced masonry in a building being reinforced be modified so as to qualify as reinforced masonry (see Jephcott, et al., 1974). This could require reinforcing for all walls rather than just the walls needed to



SECOND FLOOR SOUTH WING

Figure 5a: Second floor plan of the South Building showing location of different methods used to strengthen the structural walls.

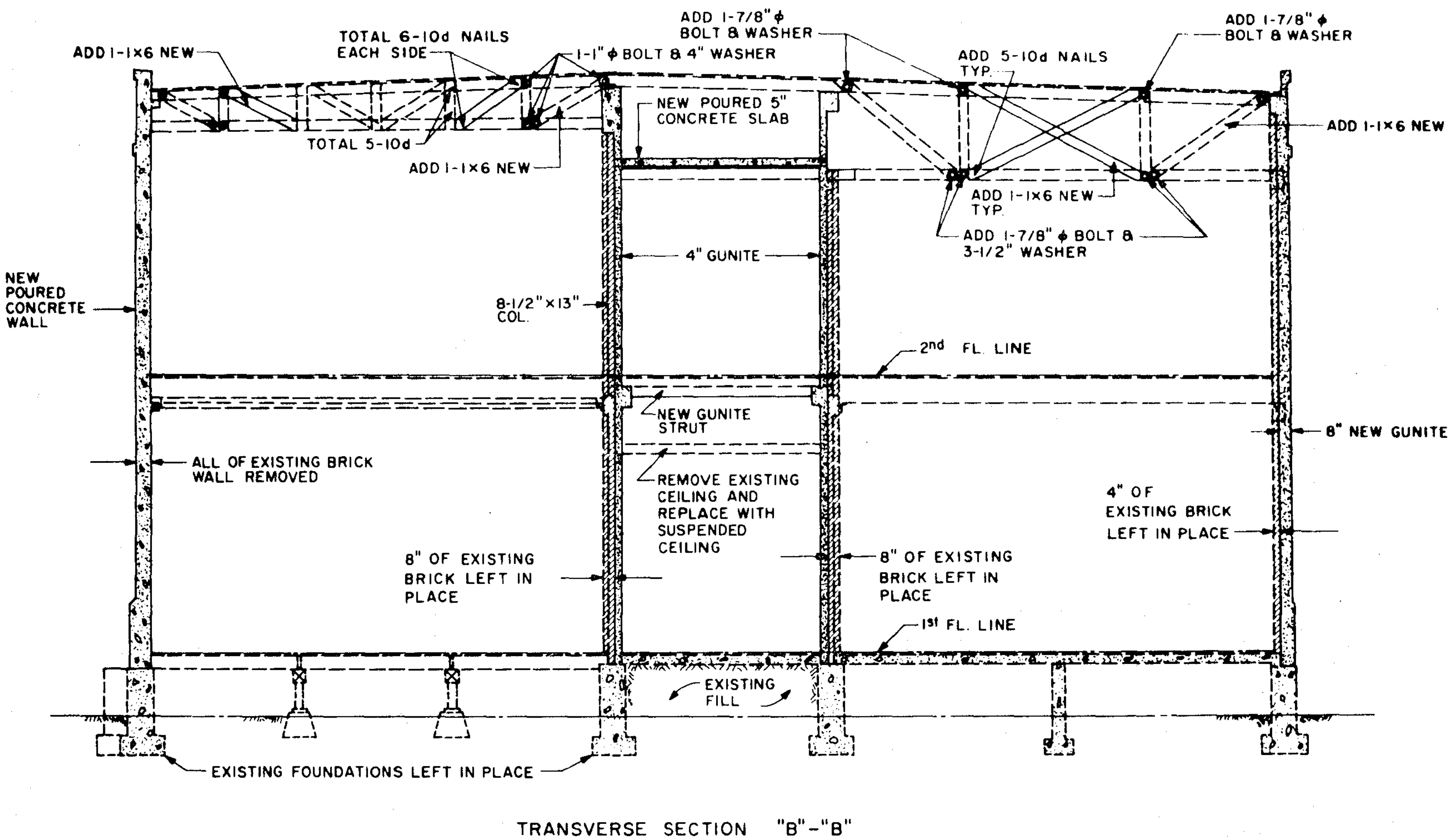
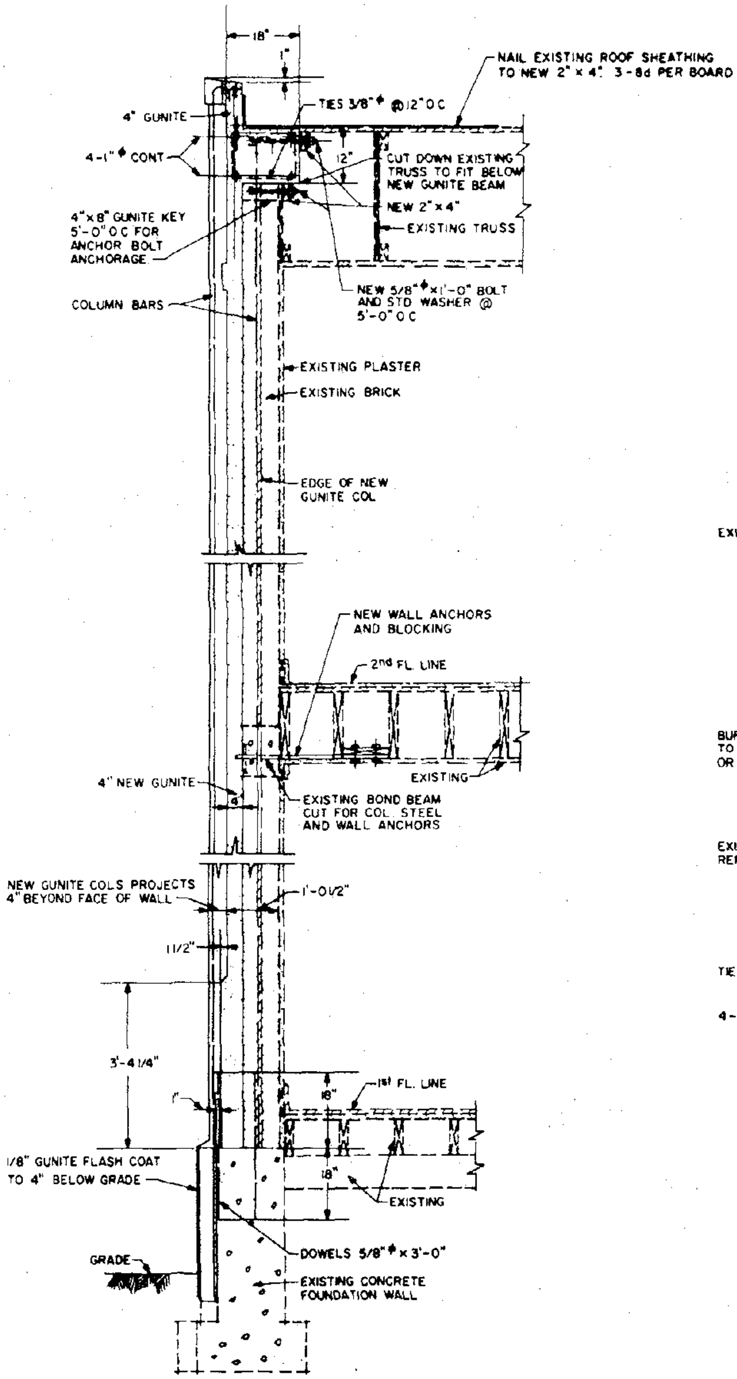
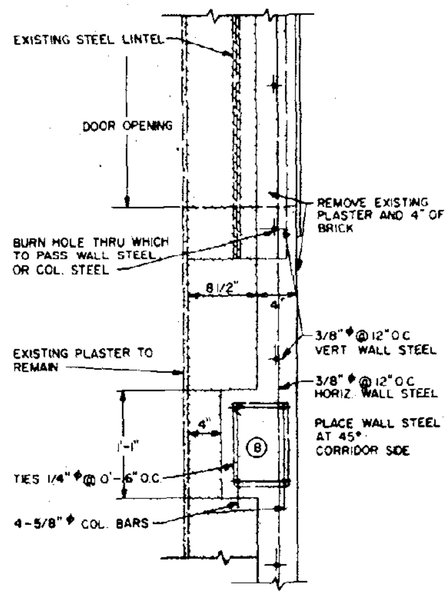


Figure 5b: **Cross section of the South Building showing details used to strengthen the structural framing.**



TYPICAL VERTICAL SECTION THRU EXTERIOR WALL



TYPICAL HORIZONTAL SECTION THRU CORRIDOR WALL

Figure 5c: **Wall sections of the South Building showing reconstruction details.**

carry the lateral loads.

Figure 5c illustrates the method of reinforcing walls by the gunite method. A layer or two of masonry is removed and replaced with an equivalent thickness of reinforced gunite. At regular intervals, pilasters of gunite, reinforced as columns, are set into the remaining masonry to tie the two materials together. At the top of the wall at the roofline, the gunite is formed into a beam over the remaining wall; the roof is then tied to this beam.

The roof and floor diaphrams also required strengthening. At the floor level this consisted of tying the floors to the walls (see Figure 5c) and adding a concrete strut or beam to connect adjacent shear walls over a corridor. At the roof level the diaphram consists of the lower chords of the wood trusses plus a new 5" concrete slab at the same level over the corridor (Figure 5b).

The adequacy of this reinforcing method was demonstrated during the 1971 earthquake--the building sustained only one minor crack in the basement.

REINFORCING IN PRACTICE

Reinforcing Buildings in Long Beach

The City of Long Beach has gone the farthest of any municipality in requiring the strengthening of privately owned buildings. Since 1959, the city building department has been working to remove or upgrade earthquake hazardous buildings built prior to the beginning of the earthquake building code in 1933 (O'Connor, 1975). Of the many buildings that have been condemned by the city, few have actually been strengthened (McClure, 1973).

For every one building that is strengthened, 6 are torn down. Other owners have appealed the condemnation. Under the ordinance that has been in effect since 1971, the building is given a hazard classification. One way to change the hazard classification is to change the use and occupancy of the building; this has been done in some cases.

For masonry bearing wall buildings (which are the majority of the pre-1933 buildings) the city requires reinforcing methods similar to those specified in Title 21 for schools (O'Connor, 1975). Mr. Charles Curtis, a structural engineer in Long Beach, has evaluated many condemned buildings and designed reinforcement for some when that solution was elected by the owner. His repair work consists of reinforcing masonry walls with a gunite layer or with a concrete pilaster set into the wall. Floors and roofs are tied to the walls. The buildings can be categorized as follows: one story industrial or garage buildings with masonry bearing walls and wood roofs, two story commercial buildings with wood floors and roofs, and three story apartment buildings with masonry walls, wood floors and roof and many wood partitions.

Most of the reinforcing has been done to industrial and commercial buildings. Since these income producing properties and the owners bear the entire cost, there is a strong incentive to make the repair work as economical as possible. The reinforcing is not as elaborate as that illustrated in Figure 5. Mr. Curtis estimates that the costs range from \$3 to \$8 per square foot.

Variations in cost depend on several factors identified by Mr. Curtis. If the building is on an interior lot and the walls must be worked on from the inside, the costs are higher. If previous strengthening of any sort was done, the costs are lower. After the 1933 earthquake, many buildings were repaired or reinforced by the construction of 'bond beams' on the tops of masonry walls, the tying of floors and roofs to the walls or the removal of parapets. The costs for apartment buildings are expected to be higher because the many partitions interrupt the diaphram of the floor but are not counted by the Long Beach code as acting to resist lateral loads in masonry buildings.

Reinforcing Veterans Administration Buildings

Since 1971, the Veterans Administration has been engaged in an evaluation of all its buildings in this country for seismic resistance (Bolt, et al., 1975).

Buildings in California received the first attention because the hazard was clear. Many of the buildings were built in 1950 to accepted earthquake standards; most were constructed with a concrete shear wall system. One group of buildings, the Sepulveda facility, received very little damage from the strong shaking during the San Fernando earthquake. Damage was limited to masonry cracking where adjacent buildings moved and distorted the seismic joint (Johnston, 1971). With this experience and the checking of structural plans, all the recently constructed buildings in California were judged safe.

Three sites had buildings which had not been designed for seismic forces. Most of these buildings were too costly to reinforce and so were demolished. At the Livermore site, the deficient buildings were reinforced.

The Evaluation Program. Buildings elsewhere in the country were examined next. Buildings located in Uniform Building Code (UBC) zones 0 to 1, where the earthquake risk is low, were excluded. For buildings located in the UBC zones 2 and 3, consultants in engineering geology and seismicity evaluated the risk of earthquake. They assigned an expected maximum intensity and an expected maximum peak ground acceleration. For those sites which had a peak ground acceleration larger than 0.1 times gravity or an intensity greater than MMI VII, the buildings are being examined in a two phase process.

Phase 1 is an evaluation of the buildings to see if they conform to the Veterans Administration's criteria. Phase 2 estimates the reinforcing cost for those buildings which do not conform. This work is being done by Architect-Engineer Consultants under contract with the Veterans Administration. To date all of the 48 sites located in zones 2 and 3 have been investigated in phase 1. The phase 2 studies are nearing completion.

The reports of these consultants were provided by the Veterans Administration and are used in the study in Chapter 3. The consultants' evaluation was for potential hazards and their recommendations should not be considered to be congruent with Veterans Administration policy.

Reinforcing at Boise. Reinforcing work has actually been carried out at the Veterans Administration facility at Boise, Idaho. The buildings have reinforced concrete frames with brick exterior walls or have brick bearing walls.

The reinforcing (to a UBC zone 3 force level) was done by removing the outer layer of brick and replacing it with a reinforced grout space and a new brick facing. This method was selected because one of the criteria for this project was the preservation of the appearance of the buildings, some of which dated from 1907. The average cost for the 10 buildings which were reinforced was $28 per square foot. This cost was fairly close to the cost estimated during the phase 2 study.

Some Individual Buildings

Other strengthening programs, including the school buildings in California, are described in McClure (1973). Several single buildings not part of a general program are being reinforced. Two similar projects are the strengthening of the California State Capital Building in Sacramento and the proposed renovation of a building at a Bay Area University. John A. Blume Associates is structural engineer for both.

Both buildings were valued for their exterior appearance so strengthening could not be added to the outside. The strengthening method proposed consisted of replacing the entire floor with a reinforced concrete flat plate system and applying reinforced gunite to the interior side of every masonry wall. In the university building, the entire inside was removed and an extra floor added. Based on the new floor area, the strengthening alone is estimated to cost $90 per square foot.

The State Capital building is being renovated partly because of its historic value; earthquake strengthening is a major part of the $43.5 million project. Exterior ornamentation is being secured to resist earthquake forces. Interior paneling and floor tile is being saved to be put back in place. The restored office space is estimated to cost $500 per square foot (Wood, 1976); about one third of this cost is for seismic strengthening.

In contrast, a hospital building in Boston was strengthened in a much more economical manner. A new building was being constructed next to and above this 4 story brick bearing wall building (which was being renovated). Both the new and old building were required to comply with UBC zone 2 requirements. One proposal to strengthen the existing building was to apply reinforced gunite concrete to the entire outside at a cost of about $600,000 to $700,000. The alternative which was selected relied on the strength of the 4 main bearing walls in one direction but added a single concrete shear wall in the other. Exclusive of other renovation costs, this reinforcement cost about $100,000. This compromise solution was felt appropriate for a building in an area where the earthquake threat is much less than in California.

CHAPTER 3

COST OF REINFORCING FOR EARTHQUAKES

Information from two of the reinforcing programs discussed in Chapter 2 forms the basis for the present examination of reinforcing costs. The Veterans Administration (VA) and the Los Angeles City Unified School District have provided information on completed or proposed reinforcing work on buildings they own. To make comparisons, it is necessary to examine the design assumptions and methods used in establishing the costs.

COST DATA ON REINFORCING VA BUILDINGS

To date the VA has received phase 2 reports on 19 of the 48 sites. Phase 2 reports include proposals for strenghtening non-conforming buildings identified during phase 1 and estimated costs for executing the work. All 129 buildings at the 19 sites, including the conforming buildings, will be included. Four sites have 15 or more distinct buildings and seven sites have three or fewer distinct buildings. The 129 buildings are listed in the Appendix with their structural type, the proposed or executed reinforcing, and the estimated cost in dollars per square foot.

The VA Lateral Force Criteria

The consultants evaluated the buildings and recommended strengthening for conformance to the VA design standard, Handbook H-08-8 (VA, 1974), (Bolt, et al., 1975). Some of the evaluations done prior to the completion of Handbook H-08-8 were based on the Uniform Building Code (UBC)

1970 or 1973 editions, as were the Los Angeles school buildings. Consequently, a comparison of the two codes will be helpful.

Handbook H-08-8 is similar to the UBC code in that both are equivalent static methods. The principle difference is the computation of the base shear V; in a Handbook H-08-8, V is given by

$$V = a \times DAF \times alpha \times W$$

where: a is the peak ground acceleration as given in Handbook H-08-8 for each site;

DAF is the dynamic amplification factor and varies with the period of the building, for all building periods less than .5 seconds, DAF = 3.0;

alpha = a number which reflects the ductility and the certainty of the performance of the structural system. Varies from 1/4 to 3/4;

W is weight of building.

The distribution of the shear over the height of the building is identical to UBC.

Almost all buildings examined in this chapter are short, stiff structures so that a single numerical comparison of Handbook H-08-8 and UBC will suffice. For box-type lateral force resisting systems less than 5 stories tall, C is about 0.10 and K equals 1.33 in the UBC base shear formula. In the VA formula, DAF equals 3 and alpha equals 1/2 (alpha could be as low as 1/3 or as high as 2/3, but 1/2 was used most often). Knowing that the VA base shear is an ultimate load we can write,

$$a \times 3.0 \times 0.5 \times W = Z \times 1.33 \times 0.10 \times W \times \frac{1.4}{0.9}\ .$$

For UBC zone 3, z equals 1.0 so the equivalent VA peak ground acceleration is 0.14 times gravity. Likewise, 0.07 times gravity is about equal to UBC zone 2 (for these buildings).

Variations in Design

Using either Handbook H-08-8 or the UBC Code, the consultants computed consistent values for base shear. However, like many codes, these two specify criteria but not rigid methodology, so there was some variation in the methods and assumptions used by the consultants in their analysis.[+]

Of the 129 buildings, 80 were evaluated by two consultants and the remaining 50 by 8 others. About 110 buildings were analyzed by consultants who used a similar approach. This approach is characterized by 1) an explicit accounting for the stiffness of masonry in distributing forces; 2) provisions for stiffening flexible floor diaphrams; and 3) the use of proven reinforcement methods. The consultants who evaluated the balance of the buildings used other methods and recommended a wider range of strengthening solutions. Nevertheless, it is reasonable to study all of the buildings together. There are real differences of opinion on what strenghtening methods are sufficient for various levels of ground shaking. The differences in methodology will have to be considered one of the major sources of variance in the cost estimates.

+A methodology for the evaluation of masonry was suggested; see Fattal (1975).

Cost Estimates

Most of the cost estimates for the proposed strengthening were made between 1973 and 1975. Due to the uncertainties of estimating, adjusting prices for inflation would be an over-refinement. All prices are assumed to be 1975 prices.

As specified in Handbook H-08-8, all price estimates include the cost of structural strengthening, restoring of finishes, relocating mechanical and electrical fixtures and overhead. No cost for other rehabilitation work is included in the cost estimates.

Handbook H-08-8 called for the "investigation and solution for proper support and attachment of electrical (and major mechanical) equipment" (VA, 1974). The costs for this work are small in comparison to the costs of relocating mechanical and electrical distribution ducts to accomodate the structural changes. For the buildings studied, the cost of bracing mechanical and electrical equipment is a negligible fraction of the total reinforcing cost.

COST DATA ON REINFORCING LOS ANGELES SCHOOLS

Mr. William A. Lamb, Chief Structural Engineer of the Los Angeles City Unified School District, has provided a list of various school buildings which were reinforced for earthquake loads and the cost of the reinforcing work at each school. All of the costs are based on actual bid prices of work completed or underway. A total of 27 school buildings are listed in the Appendix. The design requirements for reinforcing work are discussed in Chapter 2.

Cost Estimates

When a school is strengthened it is usually rehabilitated to improve the quality of the school as a teaching facility. As a consequence, the price of the work done includes many items which were not required for earthquake strengthening. However, the engineers were paid for their work in such a way that it was necessary to separate the structural cost from the other costs in the bid price. Since the structural work was almost always exclusively for earthquake, it's cost is then an estimate of the cost for earthquake strengthening.

Since the reinforcing work on these buildings is from a period covering 15 years, it was felt desirable to adjust all the structural prices to 1975 dollars. This was done using the Engineering News Record Building Cost Index for Los Angeles (ENR, 1976).

Mr. Lamb has estimated that $2 per square foot of the non-structural costs were necessitated by the earthquake strengthening; this cost was primarily for replacing the finished surfaces on repaired walls and floors. The prices listed in the Appendix are the structural costs in 1975 dollars plus $2 per square foot. These costs are comparable to the VA costs.

ANALYSIS OF REINFORCING COST DATA

The sampling of reinforced buildings listed in the Appendix will be organized in several ways to explore which factors contribute to higher or lower reinforcing costs. Potential factors include the type of structural system, the new level of seismic resistance, the age of the building, and previous seismic design or repair.

Figure 6a is a histogram of the reinforcement costs of all VA buildings and Figure 6b is a histogram of all Los Angeles (LA) school buildings. These are separate histograms because the VA data includes some special categories. The LA school data is only for buildings which did need reinforcing--there are no buildings in the "no reinforcement required" category. The VA data includes some buildings for which the estimated reinforcing cost is very high, equal to or exceeding typical costs for new construction. According to Mr. Lamb, when the reinforcing cost for a Los Angeles school building exceeds 70 or 80% of the cost of new construction, the building is replaced. Consequently, there are no costs above $25. or $30. per square foot.

Influence of Building Type

The most fruitful division of the buildings is by structural type. Five categories which cover the range of buildings studied are 1) masonry bearing wall with wood or concrete floors; 2) reinforced concrete frame with masonry infill walls; 3) reinforced concrete bearing walls with wood or concrete floors; 4) steel frame; and 5) wood frame. A separate histogram for each type is plotted in Figure 7.

Concrete Frames and Masonry Bearing Walls. Figure 7a shows that masonry bearing wall buildings, the largest single type, have some of the highest individual reinforcing costs. The reasons for these high costs will be discussed below. Even excluding the very high cost buildings, this type still has the highest average reinforcing cost. Also (when the upper tail is excluded) the VA and LA school data are very consistent.

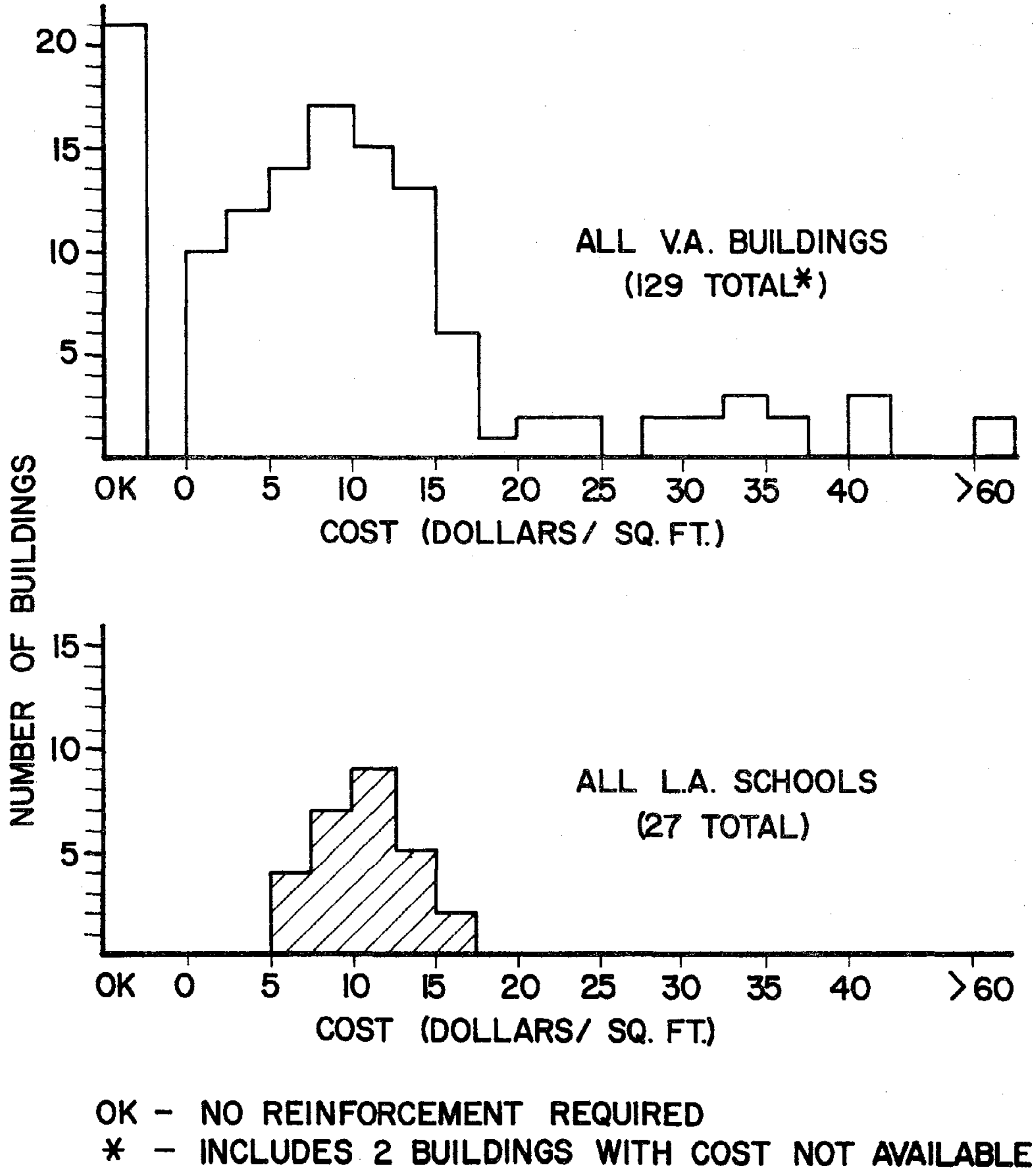


FIGURE 6 - REINFORCING COSTS FOR ALL BUILDINGS

Reinforced concrete frames with masonry infill (Figure 7b) also have a high average cost but less than the masonry bearing wall buildings. Both of these types are strenthened by the addition of new shear walls of reinforced masonry, reinforced concrete or reinforced concrete tied to the existing unreinforced masonry. This is a more extensive procedure than the bracing of wood or steel frames.

The higher cost for masonry bearing wall buildings relative to the concrete frame buildings is due to the strenthening required for wood floors and roofs which most masonry bearing wall buildings have. Because of the good qualities of concrete floors as diaphrams, usually the spacing of shear walls can be increased over the spacing required by wood floors; this also lowers the cost of concrete frame reinforcing.

Wood Frame, Steel Frame, and Concrete Wall. Figures 7c, d, and e show that the reinforced concrete wall, wood frame and steel frame buildings have considerably lower average costs than for the two types above. As one might anticipate, these types of buildings have good natural resistance to earthquakes which codes and engineers recognize. When reinforcing is needed, the methods are generally more economical than for masonry or concrete frame buildings. Wood buildings require some extra bracing or a plywood shear wall; concrete wall buildings have many elements which already qualify as shear walls; steel frame buildings, even if not constructed as moment-resisting frames, have connections which can withstand greater deformations than non-moment-resisting concrete frames.

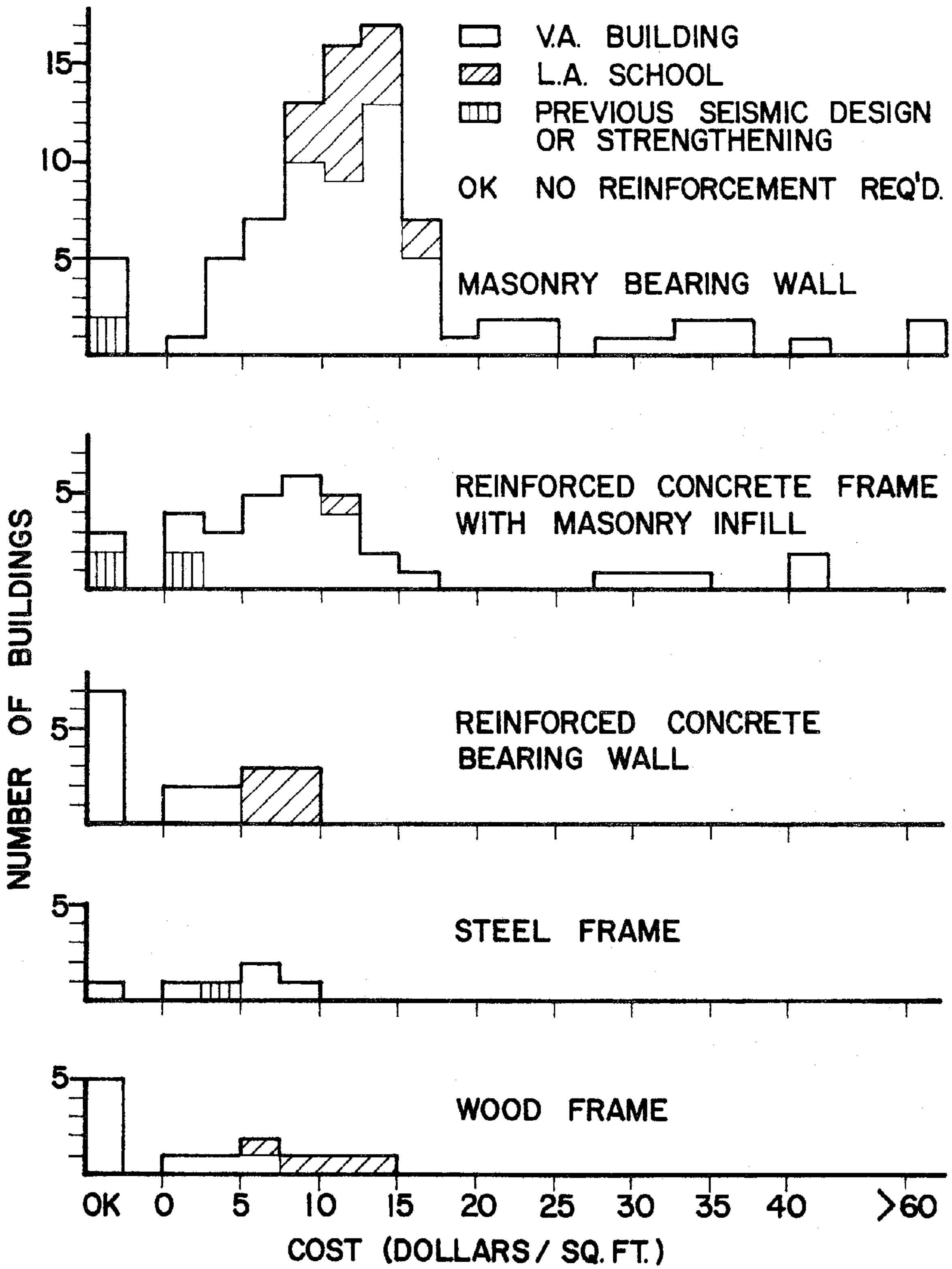


FIGURE 7 - EFFECT OF STRUCTURAL TYPE ON REINFORCING COST

Other Building Differences. The costs of the LA school buildings are clearly higher than the costs of VA buildings for concrete bearing wall and wood frame types. The consistency of the two sources for masonry bearing wall buildings suggests that the difference is something other than differences in forces or standards. Physical differences between the buildings of the same type may account for the higher cost. The wood frame buildings at VA sites are typically houses or barracks buildings of stud wall construction. The wood LA schools are mostly assembly buildings which are one story structures with a single span roof. This framed timber construction does not have as high a degree of seismic resistance as stud wall construction.

The concrete bearing wall buildings at VA sites are often boiler plants or shops. These one story buildings have no interior finished surfaces and require only roof strenthening. The LA school buildings are conventional two story buildings often with wood floors.

Buildings Needing No Reinforcement. Buildings which had been designed to some earthquake standard or had been previously reinforced are indicated in Figure 7. These are most of the buildings which did not need reinforcement for the masonry bearing wall and concrete frame types. However, the concrete bearing wall and wood frame types contribute many more buildings which conformed without reinforcing work. Altogether, about one building in seven from this VA sample needed no reinforcing work.

Influence of Design Level

Since most of the data are for masonry bearing wall buildings (which have the widest range of reinforcing cost) these buildings will be examined for the influence of the level of seismic design on cost. As shown above, all design forces can be converted to 1973 UBC zone levels. The masonry bearing wall buildings are divided into three groups by design level: group a - zone 2 to 1.5 times zone 2, group b - zone 3 to 1.5 times zone 3 and group c - 2 times zone 3. No buildings were examined for reinforcing to zone 1 design forces. Figure 8 compares the cost of reinforcing for these three groups.

Group c buildings are all from one site and so are not a reliable indicator. Ignoring for the moment the very high costs in group a, a comparison of the costs in groups a and b (Figure 8a and 8b), shows that on average buildings designed to higher lateral forces cost more to reinforce. This is confirmed by the close agreement of the LA school building costs, which are all zone 3, with the majority of the rest of the zone 3 to 1.5 times zone 3 group. However, the wide dispersion of the costs of the buildings in group a makes the average difference of a few dollars per square foot tentative.

Influence of Building Size

The size of the building is an important factor in cost. The reinforcement costs, in dollars per square foot, of the VA buildings and the LA schools were compared with gross floor area. Possibly due to the wide variety of buildings and designers, the VA data was inconclusive. The LA school data showed a trend--smaller masonry bearing wall buildings cost

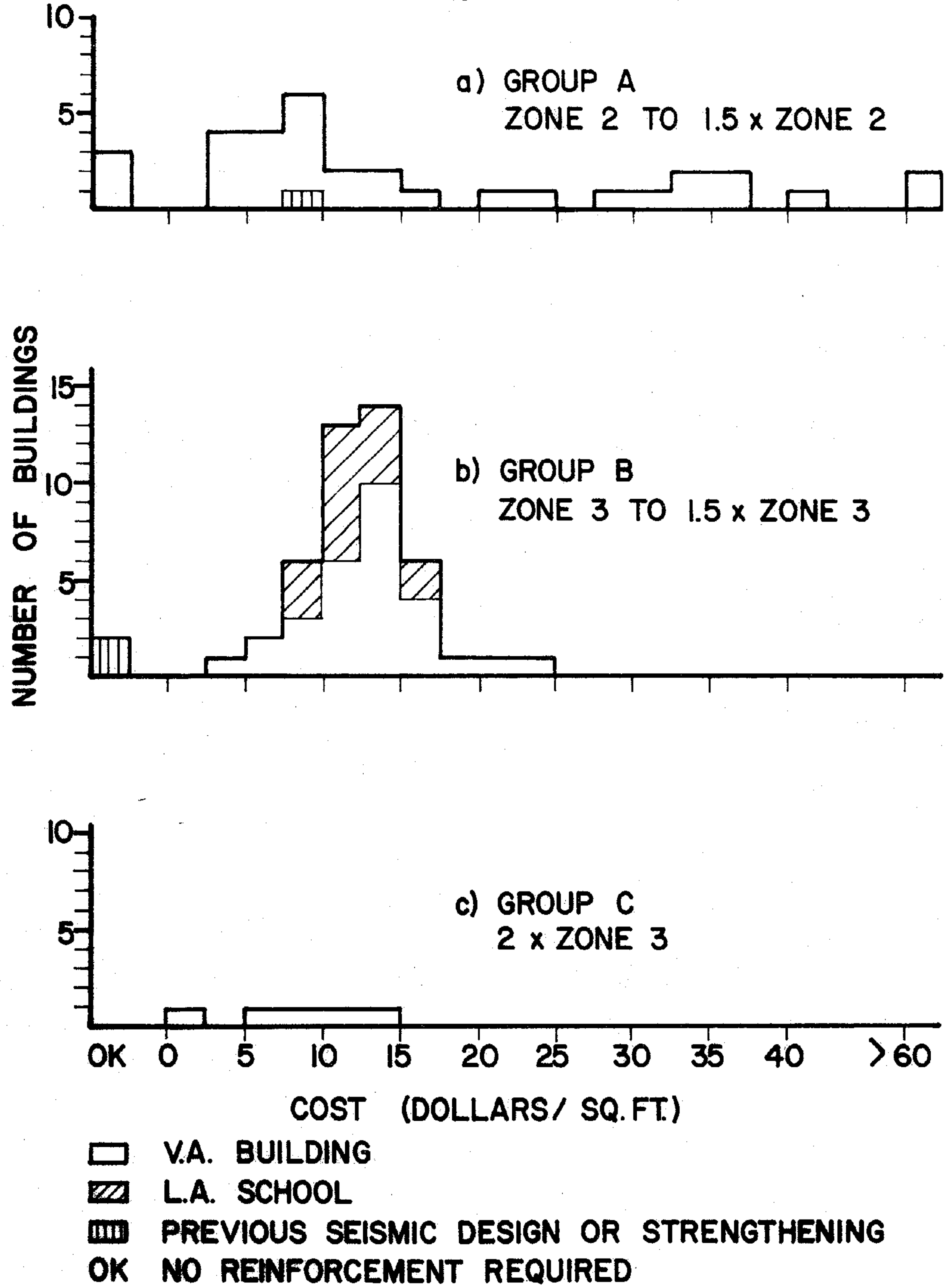


FIGURE 8 - EFFECT OF NEW EARTHQUAKE DESIGN LEVEL ON THE COST OF REINFORCING MASONRY BUILDINGS

more (see Figure 9).

Higher costs for smaller floor areas have at least three sources: 1) on larger construction projects, overhead costs can be divided by more area; 2) if a building is larger because it has more stories, the cost of bracing the roof can be divided by more area; and 3) a building with a greater area on each floor has a relatively smaller exterior wall surface. Each of these is a factor in the cost of new construction, too, as identified by Steyert (1972). The last is a particularly important source for the LA schools since the specifications require all masonry walls to be reinforced (see Jephcott, 1974). The smaller school buildings, besides having less floor area relative to the length of the exterior wall, have most of their masonry walls on the exterior.

Figure 9 suggests that reinforcing for school buildings with floor areas less than 20,000 square feet costs significantly more. Particular VA buildings show this trend also, as discussed below.

Figure 9 illustrates another reason why the wood school buildings cost more per square foot than other wood buildings--the schools are very small, 3600 square feet of floor area.

High Costs and Historic Buildings

The very high reinforcing costs for some of the buildings in Figure 8a are the result of the combination of the above factors. First, eight of the twelve buildings over $30 per square foot are from the same site and so were evaluated by the same consultant. Second, all of the buildings at this site (including those with lower costs) required extensive modifications due to flexible wood roofs and tall, unsupported attic

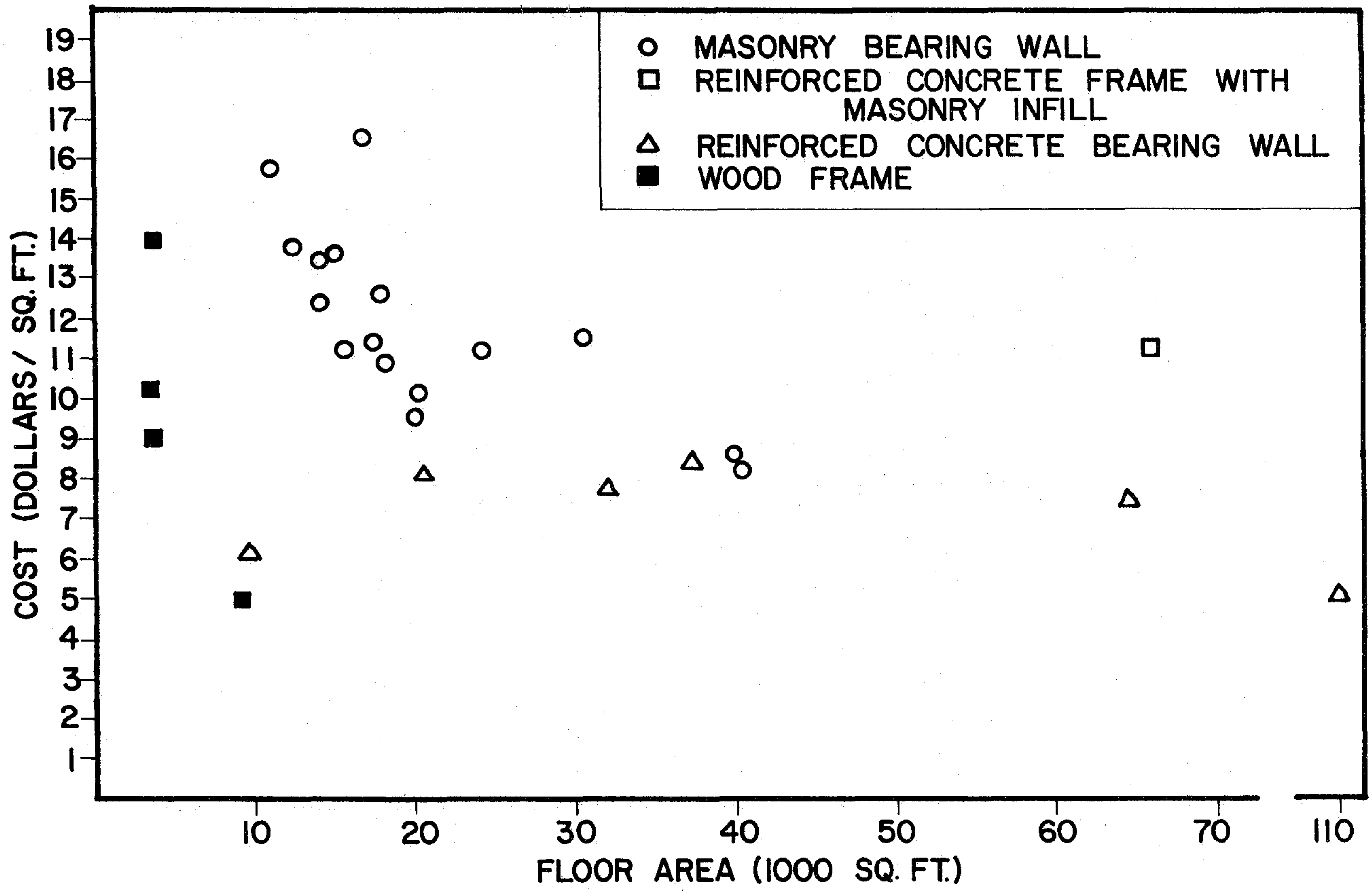


FIGURE 9 - EFFECT OF FLOOR AREA ON THE COST OF REINFORCING L.A. SCHOOL BUILDINGS

walls. The buildings which also have small floor areas (again less than 20,000 square feet) have the costs over $30 per square foot.

Another source of high reinforcement costs are special requirements to preserve the original appearance of a building. The average cost of $28 per square foot at the Boise site (Chapter 2) are on the upper side of the majority of estimates for masonry bearing wall and reinforced concrete frame. Some of the highest projected reinforcing costs, the California State Capital and the companion university building, are due in large part to the requirements that the reinforcing be done from the inside. Applying gunite from the inside is more difficult and more of the interior finish is disrupted. The two masonry VA buildings with costs over $60 per square foot (a library and a theater) were identified as buildings of "historic value." The substitution of steel bracing for the usual gunite coating raised the costs significantly. Finally, in some situations where a new interior shear wall is not allowed, a wood floor must be replaced with a concrete floor to carry the diaphram forces.

However, it is important to recognize that while restoration and other strict requirements cause the highest costs, combinations of other conditions can raise the cost beyond normal limits. Masonry bearing wall and reinforced concrete frame buildings are likely to cost more than the expected range if the building is small and has some other particular difficulty with respect to seismic strength.

Influence of Building Age

Acknowledging that information on the structural characteristics of a population of buildings may be limited to the date of construction,

Figure 10 presents a scattergram of the cost of reinforcing and the date of construction of the original building. The sample correlation coefficient (coefficient of determination about a straight line) for all the VA and LA school buildings is 0.15. Although the scatter is wide, the cost of reinforcing does increase steadily with age.

The underlying influence is that most of the older buildings are of masonry construction. The average construction date of masonry bearing wall buildings is 1933. Reinforced concrete walls and reinforced concrete frames have average construction dates of 1940 and 1943 respectively, while steel frames averaged 1947.

SUMMARY OF REINFORCING COSTS

Identifiable Variables of Cost

Separating cost information has revealed some clear variables of the cost of reinforcing. The structural type of the building is the most dominant. Figure 7 illustrates that most masonry bearing wall buildings cost between $5 and $17.5 per square foot for reinforcement and reinforced concrete frame buildings cost between $5 and $12.5 per square foot. Five dollars is a reasonable minimum cost for these types. Although the VA data shows some lower costs, none of the LA schools, which are completed projects and not projections, are less than $5 per square foot.

The other three structural types have a narrower range of costs, a lower maximum price, and a significant number of buildings which require no work at all. Unlike the first two, the $5 lower bound cannot be applied due to the unusual nature of some of the wood and concrete wall LA school buildings. Consequently, expected reinforcement costs vary

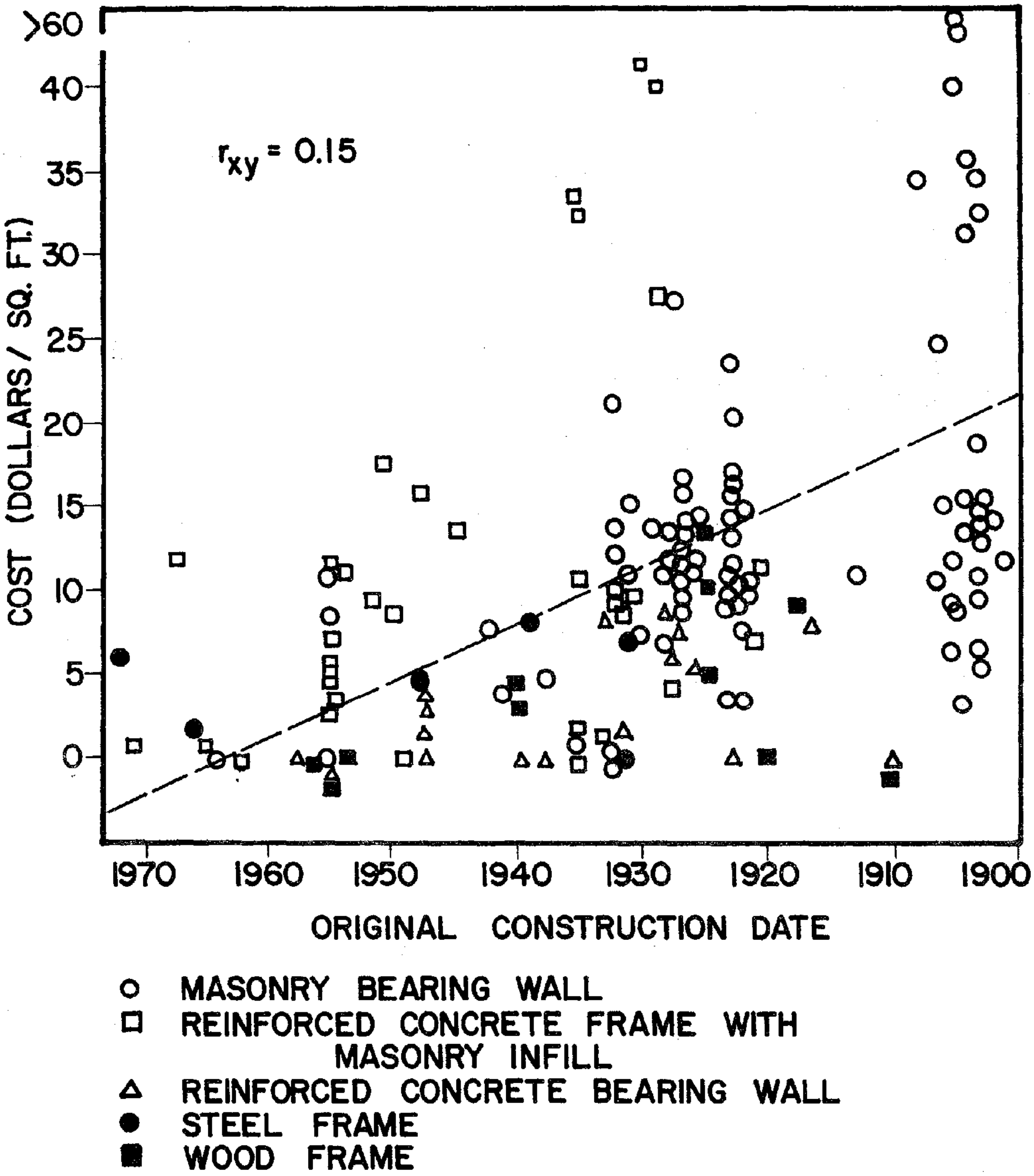


FIGURE 10 - EFFECT OF DATE OF CONSTRUCTION ON REINFORCING COST

between 0 and $10 per square foot for concrete bearing wall, steel frame and wood frame buildings.

After structural type, the size of the building is the most important of the identified variables. Buildings of less than 20,000 square feet generally have costs on the upper end or exceeding the ranges just mentioned. Costs for larger buildings do not show much sensitivity to floor area differences.

The level of seismic design has been shown to have some influence on cost, although smaller than the above two.

Finally, two other variables (which apply to a minority of buildings) cause the price of reinforcing to violate the above limits. First, a building with previous seismic design, repair or strengthening is invariably very economical to reinforcement; often these buildings need no work. Second, special requirements for the use or appearance of the reinforced building can result in a reinforcement cost from $30 to $100 per square foot for masonry or concrete frame buildings.

Sources of Variation

Within the data discussed, there are other sources of variation which have not been isolated. Some are unavoidable in a study of this kind. Estimated costs necessarily have a great deal of variability depending on the assumptions. Even costs back-figured from bid prices have some error due to variations in which costs are included. There are variations in the judgment and practice of the design engineers. One engineer might accept a slightly overstressed wall while another would require gunite for the entire wall.

A more interesting source of cost variation is the building itself. Even within one structural type and floor area there is a great range of buildings which in turn have a range of reinforcement requirements. The concrete bearing wall buildings are an example--most are identical on the surface to masonry bearing wall or concrete frame buildings. The presence of interior masonry walls (instead of wood or concrete columns) can add much strength. Narrow buildings, buildings with pitched wood truss roofs, or buildings of irregular plan often require extra work.

Standards of Reinforcement

Although the design standards were different, the costs of the LA schools and VA buildings were comparable. This is due in part to compensating factors--the LA schools required gunite on all masonry walls but many VA buildings had pitched roofs and longer floor spans requiring more floor and roof strengthening. One the whole, the thoroughness of the work appears to be comparable.

Differences in standards may account for the much lower prices for reinforcing commercial buildings in Long Beach, $3 to $8 per square foot. Private owners might be expected to achieve minimum compliance and, indeed, one would expect a superior level of safety for a school building. However, these Long Beach costs may be biased by the elimination of very high costs--any building which is very expensive to reinforce would probably be torn down. (A private owner has better investments available than an old building; a school system would still need to replace the building.) In addition, the buildings reinforced in Long Beach are not schools or institutional buildings but one and two story garages, offices, and stores. The lower costs in Long Beach are not representative of reinforcing costs for a complete population of masonry buildings. Consequently, it would be unrealistic to limit projected reinforcing costs to $3 to $8 per square foot for all masonry buildings.

CHAPTER 4

OTHER ASPECTS OF EARTHQUAKE CODES

SOME IMPACTS OF SEISMIC BUILDING CODES

As suggested in Chapter 1, the addition cost of constructing new buildings for earthquake loads will, in time, be reduced to a very low amount. Nevertheless, cost is an important parameter in the decision to employ a new or higher seismic code. Other considerations which might influence a code decision deserve attention. Two considerations are discussed below--the effect of a code on the construction industry and the economic impact on a region due to code differences.

Effects on Construction Industry

The public acceptability and successful implementation of a new seismic code (or any new building regulation) depends on the cooperation of all affected parties. Engineers, architects, contractors, materials suppliers, developers and investors all have an interest in the code because it effects their daily business.

Engineers and Designers. A thorough earthquake code requires design procedures beyond those required for lateral loadings due to wind. A designer must compute the torsion of the building due to eccentric mass or stiffness, provide ductility in members and connections for loads larger than design loads, provide for deformations beyond the design deformations and consider the interaction of the structure with non-structural elements. This will require more design time.

The ATC-2 study addressed the question of design cost incurred by using a more sophisticated response spectrum design procedure. After each of 11 engineers redesigned a building using the new procedure, they were asked to estimate how much extra design cost was incurred over the 1973 UBC method. The estimates of the engineers ranged from 5 to 30 percent extra design cost. One interpretation of the engineers' comments suggests 15% is a reasonable expected increase.

A more likely change in codes would be from no seismic code to a UBC type, equivalent static code. Since most of the design cost in the ATC-2 study was for additional analysis, this might be a fair estimate of this part. For a first time code, there would be extra expense for new detailing of concrete reinforcing, masonry isolation, etc. Even after the time when designers became accustomed to and had experience using a new code, the costs would be higher than the 15% estimated in ATC-2.

Increases of this size in design costs are negligible compared to the cost of the building, but are a considerable expense to the designer if he must absorb the entire increase. In their assessment of the proposed energy conserving ASHRAE Standard 90-75, Arthur D. Little, Inc. examined the impact on various industry participants. They projected the amount of additional billings required by architects and mechanical engineers to follow the standard, but commented that "the A/E's ability to collect for additional services will depend strongly on the health of the construction industry at the time" (ADL, 1975). The uniformity of design cost increases for all competing professionals suggests that fees could be increased to cover costs at some point in time when the industry is healthy.

Building Materials Industry. To minimize the cost increase imposed by a new earthquake code designers may specify different materials and structural systems. These changes might result in fewer masonry and pre-cast concrete buildings for example.

However, if these industries are really put at a disadvantage economically, they can be expected to introduce new methods of design or construction techniques which will restore their competiveness. If not, these materials will just take a smaller part of the market.

A new code would have a beneficial effect on certain materials, particularly steel since more reinforcing would be required in all types of buildings. The steel industry has generally given its support to codes and regulations which require higher lateral design forces and provisions for the continuity of members.

Altogether, the effect on the entire construction industry would be temporary. The various suppliers have experienced many fluctuations in the volume of business before. With many alternate building systems available, one need not be concerned with more than the short term effects of a new code on the construction industry.

Effects on Regional Development

By the very nature of the seismic hazard (or the way it is interpreted), seismic codes vary from region to region. One might be concerned with the effect of the increased costs of a seismic code on a region's economy and future growth. As one approach to this question an analogy can be made between the "social tax" of a building code and property taxes. The code tax is incurred when land is built on (or improved) as are increases in the property tax. Unlike property taxes, the code tax is paid only once at the time of construction.

In theory, the cost of the property tax is shifted forward to the final consumer, whether he is a leasee of residential property or the purchaser of the products of the business tenant (Netzer, 1966). As long as all competing rental space or businesses pay the same tax, its cost can be passed along. An exception is the business which sells in a market larger than the region of uniform taxes. Since its competitors may pay lower taxes somewhere else, the business must make up the difference. However, Netzer has suggested that the decisions of a business to locate are non-marginal with respect to property taxes. This is due to the small part property taxes contribute to the expense of doing business.

If the property tax is not critical, then so is the cost of building codes: the code tax, paid only once for a building, is much smaller than the property taxes for a single year. The implication is that the presence of a stricter building code will never be a hinderance to the development of a region.

It has been suggested that while a single regulation may never be marginal to anyone's business decision, the combination of many regulations and restrictions may be. New buildings in the United States must comply with many new regulations--wind and earthquake codes, fire regulations (such as sprinklers), provisions for the handicapped, energy conservation measures and safety regulations. It is difficult to judge what the combined effect would be if there were regional differences. This is a much broader question than a decision about seismic safety, but may be an important factor in the acceptability of an additional code.

SOME CONSIDERATIONS FOR REINFORCING

Because the cost of reinforcing existing buildings is large, the economic effect cannot be assumed to be at a low, unnoticed level. The total impact of a policy or regulation for reinforcing will vary with the comprehensiveness and time schedule of the regulation.

A mandatory regulation which requires all deficient existing buildings to comply with a new standard, such as the program in Long Beach, California, is the most severe. Each owner must bear the cost of reinforcing the building or the cost of constructing a new building. Not to be neglected is the loss of use of the building for the period when the building is being repaired. The high rate of appeals of condemnations and the number of buildings which are torn down attests to the burden of this kind of regulation on private owners.

A less drastic measure would be to require compliance only when a building is renovated. The problem of the temporary closing of the building is eliminated and the cost of the reinforcing itself is less since it is part of another construction project. Also, there is legal precedence for requiring renovated buildings to comply with the current building code. However, for private owners, the extra cost for earthquake reinforcing could become a deterrent to renovating existing buildings.

A limited program of reinforcement for selected public facilities, such as schools or hospitals, could be more easily achieved than a general program for all buildings. A subsidy for a privately owned building also would reduce owner resistance and could be an effective expenditure for increasing public safety. Any program of reinforcement generates new construction work and therefore would be beneficial to all segments of the construction industry.

THE EXISTING HAZARD

Numbers of Older Buildings

An approximate predictor of a building's repair cost is its age. A count of the number of older buildings would give an indication of the number of more hazardous buildings and more expensive reinforcing projects. The 156 buildings in Chapter 3 are not a representative sample; the census can provide an approximate estimate of the proportion of older buildings. Using only data on ages of housing units and warehouses, Wiggins (1974) has made an estimate of the ages of existing buildings in the U.S. Isolating the more expensive pre-1939 buildings, we see that in the Northeast 56% of the buildings are of pre-1939 construction, with 45% in the North Central region, 28% in the South, 24% in the West without California and 27% in California. Even accounting for possible over estimation, the Northeast and North Central regions have a sizable number of buildings that are expensive to reinforce.

Also useful is a survey of selected large cities for school buildings which were constructed prior to 1920 and still in use in 1965 (Sacks, 1972). Many cities--Baltimore, Boston, Chicago, Cleveland, Milwaukee, Pittsburgh, St. Louis, Washington--had more than 40 percent pre-1920 schools. In contrast, Houston had 20 percent pre-1920 schools and Los Angeles 8 percent. This can be attributed to the post-war growth in these cities and the fact that these cities, at least for schools, have a combined center city and suburban government. In California, where many schools have been strengthened, it was estimated in 1972 that 1,593 pre-code schools still needed to be strengthened at an estimated cost of $600 million (McClure, 1973). In the East the proportion of older school buildings would be many times the proportion in California.

Rate of Replacement

One argument against reinforcing non-conforming older buildings is that eventually they will be replaced by new buildings which are safer. However, this rate may be too slow to achieve the desired level of safety. The census can be used to illustrate the historic rate of replacement. In 1950 the City of Boston had 204,000 housing units constructed prior to 1939; in 1970 there were 167,000 pre-1939 units. In a span of 20 years, 37,000 or 18 percent of these older units were torn down. The rate of replacement of commercial and industrial buildings is probably higher since new commercial development would not remain proportional to the number of housing units within the city limits.

Table 2 presents data on the number of school rooms constructed, abandoned and in use in the United States in various years. Approximately 1/3 to 1/4 of the new construction replaces abandoned rooms. Of course, the new school is not necessarily in the same locality as the one abandoned. Also, "abandoned" does not necessarily mean the building was torn down--the space could have been shifted to other uses.

In the 10 year period between 1960 and 1971 approximately 180,000 school rooms were abandoned; this is 17% of the rooms in use in 1960. Acknowledging that the patterns of school construction (or the construction of any facility) will not remain constant and that this is a national average, we might assume that one-fifth of schools buildings in a city

Table 2: Public and Secondary School Classrooms in Use in the United States

Year	New Classrooms Constructed x(1,000)	Classrooms Abandoned x(1,000)	Classrooms Available at Beginning of Year x(1,000)
1955	63	14	1,043
1960	72	19	1,332
1964	69	16	1,549
1965	73	18	1,595
1966	71	24	1,653
1967	75	19	1,709
1968	70	18	1,765
1969	64	19	1,836
1970	62	15	1,918
1971	NA	NA	1,898

Source: Statistical Abstract of the United States, 1975, 96th Edition, Bureau of the Census.

today will be gone in 10 years. In terms of earthquakes, it is reasonable to assume that an older, more hazardous building would be selected for abandonment before a newer building. If a city has 60 percent hazardous school buildings, one-third could be eliminated by natural attrition in the next 10 years. Even under the favorable assumptions made above, this rate is still quite slow if safety is an immediate concern. In general, the natural replacement of buildings is not a simple solution to the problem of earthquake hazardous existing buildings.

Percentage of Earthquake Designed Buildings Outside California

A building originally designed for some earthquake load usually can satisfy some higher code load as well or, if not, needs only the most economical strenthening. However, earthquake design has been uncommon in this country outside California until very recently.

Prior to 1933, no earthquake design was required by any code in use, although the first edition of the UBC code in 1928 had suggested provisions for lateral bracing. Earthquake provisions were added to the building codes of Long Beach and Los Angeles in 1933; San Francisco added earthquake provisions in 1947 (and modified them in 1956) (Leslie, 1972) (Kirkland, 1962). While all school buildings in California have been designed for earthquake since 1933, other buildings constructed between 1933 and the mid-1950s may not have been.

The Model Codes. The major means of spreading earthquake design provisions has been the model building codes. The 1949 Uniform Building Code was the first to include a map showing the various earthquake zones in the country (this particular map remained through the 1967 edition).

However, until the 1961 code (when UBC also adopted the Recommended Lateral Force Requirements of the Structural Engineers Association of California (SEAOC) (Kirkland, 1962)) the code stated only "that the following provisions are suggested for inclusion in the code by cities located within an area subject to earthquake shocks" (ICBO, 1958).

The three other model codes trailed the UBC code in including seismic provisions. The National Building Code (NBC) endorsed by the American Insurance Association has included some earthquake design provisions since 1955. By at least the 1967 edition, the new SEAOC provisions were added. However, the earthquake provisions remain in an appendix not referred to in the body of the code; the preface only suggests these provisions be adopted by local authorities.

The Building Officials and Code Administrators (BOCA) Code also draws from the UBC code. The 1970 edition, while not as up to date as the UBC code, did have earthquake provisions. However all requirements could be avoided if a building was a) less than 3 stories or 35 feet in height, or b) was of skeleton frame construction and designed for some wind load and the height did not exceed 35% fo the width. Needless to say, many buildings qualify.

The Southern Building Code of the Southern Building Codes Congress did not mention seismic loads until 1973 and then only to say that where seismic design is required by local authorities, design for the loads in the ANS1-A58.1 Standard. This first reference to earthquakes appears to be the result of the inclusion of more southern states in seismic zones 2 and 3 in the 1970 UBC published map.

<u>Earthquake Codes in Use</u>. Model codes are relatively good indicators of what the largest design levels could have been in different parts of the country at different times. Field (et al., 1975) reports a survey of 919 municipalities inquiring about the basis of their building code. 91% of the municipalities in the West use the UBC Code.

In the South, 56% use the Southern Building Code and 18 percent use the National Building Code. In the North Central region, the 23% use UBC, 28% use BOCA, and 11%, NBC. In the Northeast, 32% use BOCA and 22% use NBC. The balance of the municipalities in each region use a local or state code. The low use of model codes in the Northeast is attributed to the number of cities which had their own local codes prior to the writing of model codes.

The widespread use of UBC in the West suggests that most municipalities within UBC zone 2 or 3 have some earthquake code. However, Ventre (1973) reports that local governments are often slow in adopting changes. Only 58% of the cities surveyed review their code every every year for model code changes.

East of the Mississippi one would expect seismic regulations at most where the UBC map, as reproduced in BOCA or NBC, shows areas of seismic activity--Boston, upper New York State, the Missouri-Tennessee area, and South Carolina.

Municipalities in these areas may not have incorporated or enforced the seismic provisions of the model codes in use in the area. Most areas in the South which are now UBC zone 2 areas, use the Southern Building Code and do not add their own seismic requirements. The City of Charleston follows the National Building Code, but the seismic provisions are not specifically referenced. The cities of Memphis and St. Louis adopted the BOCA Code in 1967 but specifically eliminated any seismic provisions.*

In the North, the incorporation of seismic codes has also been rare. The North Central region uses UBC but is not a seismic area; the Northeast uses BOCA and NBC, neither of which stress earthquake design.

The City of Boston rewrote its local building code in 1970. At that time it included the seismic provision of UBC zone 2. This code was in effect until 1975. However, the number of buildings designed for full compliance to the UBC code is small since there was much room for interpretation by the engineer. In 1975, Massachusetts adopted a new state code which had specially written seismic provisions. This is probably the first code in the East to consciously include seismic design requirements in a way that can be enforced.

Since 1971, some individual buildings in the Eastern United States have been designed for seismic loads such as VA owned buildings and some other buildings owned by the Federal Government. However, these are a tiny minority of all buildings.

*Information provided by Messrs Howe and Radziminski.

CONCLUSION

The problem of preventing damage and collapse of buildings during earthquakes divides itself neatly between future buildings and already existing buildings. Constructing new buildings to meet earthquake codes is relatively economical--the design professionals can be expected to adjust to a new code and in time produce earthquake resistant buildings for an additional cost so small it will be unnoticed.

In contrast, the existing building hazard has no inexpensive solution. The problem may even be more severe considering that the most hazardous buildings--now, next year and 20 years from now--are buildings which are in use today. Any program to reinforce existing buildings will be both expensive and disruptive. The adoption of a seismic building code for new construction, which can be done easily because it is economical, provides only a partial solution. The greater hazards and greater costs of providing safety in existing buildings create a much harder policy decision.

REFERENCES

Applied Technology Council, No. 2 (1974): An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings, A study report for Center for Building Technology, National Bureau of Standards, San Francisco.

Arthur D. Little, Inc. (1975): "An Impact Assessment of ASHRAE Standard 90-75, Energy Conservation in New Building Design," a report to Federal Energy Administration, December, 1975.

Blume, J.A.; Newmark, N.M.; Corning, L.H. (1961): Design of Multistory Reinforced Concrete Buildings for Earthquake Motions; Portland Cement Association, Skokie, Illinois.

Blume, J.A. (1970): "Civil Engineering and Public Safety in Design and Construction of Civil Structures," in Public Safety, A Growing Factor in Modern Design, National Academy of Engineering, Washington, D.C.

Bolt, B.A.; Johnston, R.G.; Lefter, J.; Sozen, M.A. (1975): "The Study of Earthquake Questions Related to Veterans Administration Hospital Facilities," Bulletin of the Seismological Society of America, Vol. 65, No. 4, August, 1975.

Bureau of the Census (1975): Statistical Abstract of the United States, 96th edition.

Engineering News Record (1976): "Engineering-News Cost Indexes in 22 Cities, 1950-1975," ENR, Vol. 196, No. 12, March 18, 1975.

Fattal, S.G.; Cattaneo, L.E. (1974): "Evaluation of Structural Properties of Masonry in Existing Buildings," prepared for Office of Construction, VA, by Center for Building Technology, National Bureau of Standards, Washington, D.C.

Field, C.G.; Rivkin, S.R. (1975): The Building Code Burden, D.C. Heath, Lexington.

Housner, G.W.; Jennings, P.C. (1974): "Problems in Seismic Zoning," in Engineering Seismology and Earthquake Engineering, Solnes, ed., Noordhoff, Leiden.

International Conference of Building Officials (1973): Uniform Building Code, 1973 Edition, Vol. 1, Pasadena. (Also, see 1952, 1958 and 1961 editions.)

Jephcott, D.K.; Hudson, D.E. (1974): The Performance of Public School Plants During the San Fernando Earthquake, Earthquake Engineering Research Laboratory, C.I.T., Pasadena, California.

Johnston, R.G. (1971): "Report on Investigation of Earthquake Damage to Structures at the Veterans Administration Facilities at Sepulveda, California," prepared for VA Office of Construction, Brandow and Johnston, Los Angeles.

Johnston, R.G. (1975): "Review of Earthquake Resistant Design Requirements for VA Facilities," in Report of the Earthquake and Wind Forces Comm., Office of Construction, VA, Washington, D.C.

Kirkland, W.G. (1962): The Agadir, Morocco Earthquake, American Iron and Steel Institute, New York.

Lefter, J.; Colville, J. (1975): "Reinforcing Existing Buildings to Resist Earthquake Forces," Proceedings of the U.S. National Conference on Earthquake Engineering, Ann Arbor, June, 1975.

McClure, F.E. (1973): "Survey and Evaluations of Existing Buildings," in Building Practice for Disaster Mitigation, National Bureau of Standards, Building Science Series No. 46, GPO, Washington, D.C.

Netzer, D. (1966): Economics of the Property Tax, Broockings Institute, Washington, D.C.

O'Connor, E.M. (1975): "Correcting Existing Earthquake Hazardous Buildings in the City of Long Beach, California," Proceedings of the U.S. National Conference on Earthquake Engineering, Ann Arbor, June, 1975.

Picardi, E.A. (1973): "Structural System - Standard Oil Building of Indiana," American Society of Civil Engineers, Journal, Vol. 99, No. ST 4, April, 1973.

Sacks, S. (1972): City Schools/Suburban Schools, A History of Fiscal Conflict, Syracuse University Press, Syracuse.

Sanderson, R.L. (1969): Codes and Code Administration, An Introduction to Building Regulations in the United States, Building Officials Conference of America, Chicago.

Steyert, R.D. (1972): The Economics of High Rise Apartment Buildings of Alternate Design Configurations, American Society of Civil Engineers, New York.

Ventre, F.T. (1973): Social Control of Technological Innovation: The Regulation of Building Construction, Ph.D. thesis, M.I.T. Department of Urban Studies and Planning, Cambridge.

Veterans Administration (1974): "Earthquake Resistant Design Requirements for VA Hospital Facilities, Handbook H-08-8," in Report of the Earthquake and Wind Forces Committee, 1975.

Whitman, R.V.; Biggs, J.M.; Brennan, J.; Cornell, C.A.; deNeufville, R.; Vanmarcke, E.H. (1974): Methodology and Pilot Application, Seismic Design Decision Analysis Report No. 10, M.I.T., Department of Civil Engineering Research Report, R74-15.

Wiggins, J.H. (1974): "Budgeting Justification for Earthquake Engineering Research," a report prepared for National Science Foundation, by J.H. Wiggins, Co., Redondo Beach.

Wood, L. (1976): "California to Restore Its Century-Old Capital," Christian Science Monitor, Vol. 68, No. 104, April 23, 1976.

Leslie, S.K. (1972): Earthquake Code Evolution and the Effect of Seismic Design on the Cost of Buildings, M.S. thesis, M.I.T. Department of Civil Engineering, Cambridge.

APPENDIX

REINFORCING COST DATA

Table A-1 lists all of the buildings used as data in the analysis of reinforcing costs in Chapter 3.

Table A-1

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-VA						
Mt. Home-70	1904	2:28,000	.1g	3,4,5,6,7	15.3	
Mt. Home-70	1905	1:16,600	.1g	2,14	62.7	g,h,i
Mt. Home-24	1905	1:4,400	.1g	7,	42.3	
Mt. Home-20	1904	2:6,500	.1g	4,5,7	36.5	
Mt. Home-53	1908	2:3,900	.1g	4,7,6,13	34.1	
Mt. Home-52	1903	2:13,900	.1g	3,4,7,6	34.2	
Mt. Home-34	1903	2:53,000	.1g	7,11,2,6	32.5	
Mt. Home-28	1904	1/2:14,000	.1g	6,7,15,1	35.9	
Mt. Home-17	1904	2:5,400	.1g	1,7,14	57.0	i
Mt. Home-1	1905	3:56,00	.1g	7,5,9,3	9.3	
Mt. Home-73	1932	2:22,600	.1g	1,11,7	21.2	j
Mt. Home-95	1941	1:5,400	.1g	3	3.5	k
Mt. Home-60	1905	3:38,100	.1g	3,4,7	6.1	l
Mt. Home-50	1903	1:13,600	.1g	17,	-	
Mt. Home-69	1903	3:18,500	.1g	7	6.2	
Mt. Home-74	1902	3:28,400	.1g	4,15,5,6	14.0	
Mt. Home-7	1904	3:42,400	.1g	7,5,3,16	13.4	

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-VA						
Mt. Home-3	1905	3:38,000	.1g	7,5,3	11.9	
Mt. Home-13	1905	1:6,300	.1g	7,6,13	9.0	g,h,m
Manchest-11	1888	3:6,800	.12g	ok	-	
Roseburg-4	1932	2:3,800	UBC 2	ok	-	
Roseburg-10	1932	1:4,800	UBC 2	ok	-	
Walla-74	1922	2:26,800	UBC 2	1,7,18	9.2	
Walla-68	1906	2:49,300	UBC 2	14,1	24.8	i
Walla-41	1888	N/A:6,000	UBC 2	N/A	5.3	
Walla-65	1904	N/A:8,700	UBC 2	N/A	2.8	
Walla-77	1927	1:3,600	UBC 2	19,7	27.6	
Walla-66	1937	1:11,500	UBC 2	1,7	4.9	j
Walla-75	1922	1:20,500	UBC 2	1,3	2.9	j
Walla-81	1928	1:6,300	UBC 2	1	6.8	j
Walla-76	1921	1:4,700	UBC 2	1	9.8	j,h,O
Walla-78	1930	1:16,000	UBC 2	1,7	7.6	j,g
Walla-82	1932	2:7,800	UBC 2	3,7	12.2	j
White-203	1942	2:24,000	UBC 2	3,7,5	7.7	p
Augusta-20	1913	4:35,400	0.18g	1,11,4	10.9	
Augusta-7	1923	1:22,800	0.18g	11,2,14	2.9	
American-18	1928	1:21,300	1.5xUBC 3	1,8,7	10.8	
American-5	1923	1:9,500	1.5xUBC 3	1,11,9,8	23.2	j
American-3	1923	1/2:25,800	1.5xUBC 3	1,11,8,9	14.0	j
American-17	1922	2:6,600	1.5xUBC 3	1,8,9	10.3	j

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-VA						
American-2	1923	2:51,300	1.5xUBC 3	1,3,8,9	11.9	j
American-12	1923	2:3,700	1.5xUBC 3	NA	9.2	
American-9	1923	2:10,900	1.5xUBC 3	1,7,8,9	13.1	j
American-7	1920's	2:21,900	1.5xUBC 3	1,11,8,9	14.2	j
American-6	1923	2:22,300	1.5xUBC 3	1,11,8,9	16.0	j
American-4	1923	2:23,000	1.5xUBC 3	1,11,8,9	20.2	j
American-61	1931	3:44,200	1.5xUBC 3	1,11,8,9	15.7	j
American-16	1922	2:5,900	1.5xUBC 3	1,8,9	10.3	j
American-8	1923	3:16,600	1.5xUBC 3	1,11,8,9	16.4	j
American-23	1923	1:3,500	1.5xUBC 3	1	16.5	j,0,h
American-50	1922	1:5,700	1.5xUBC 3	1,3,6	7.2	j
American-17	1924	1:10,000	1.5xUBC 3	14,13,8	9.5	j
Prescott-15	1903	1:11,700	.15g	7,6,3	18.5	g
Prescott-19	1903	1:2,100	.15g	7,20	9.3	
Prescott-42	1903	1:3,900	.15g	7,3,6	10.9	
Prescott-16	1905	1:3,500	.15g	7,1,6	14.8	
Prescott-70	1922	2:19,900	.15g	3,4,5,6,7	14.6	
Prescott-28	1903	2:9,100	.15g	20,3,4,6,7	14.7	
Prescott-20	1903	2:11,700	.15g	4,3,5	5.4	
Prescott-17	1903	2:4,800	.15g	4,5,6,3,2	14.6	
Prescott-14	1903	2:34,300	.15g	4,3,7,5	12.7	
Prescott-12	1903	2:15,000	.15g	4,3,7,5	14.0	
Seattle-11	1950's	1:6,500	UBC 3	ok	-	q

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-VA						
Seattle-13	1964	2:19,400	UBC 3	ok	-	q
Harrison-150	1935	2:13,700	0.30g	3,10	0.9	
Harrison-2	1906	2:14,200	0.30g	4,5,3,6,18	10.4	
Harrison-20	1892	?:15,600	.3g	3,7,20	6.7	
Harrison-31	1900	1:3,300	.3g	7,3,6	11.5	
Harrison-47	1955	2:9,700	.3g	3,4,5,6,7,20	8.6	
Salt-7	1950's	1:22,200	UBC 3	19,3	11.3	
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-LA SCHOOLS						
Aldama	Pre-1933	2:11,400	UBC 3	21	15.8	
Aragon	Pre-1933	2:16,300	UBC 3	21	16.2	
Bridge St.	Pre-1933	2:12,500	UBC 3	21	13.9	
Carthay	Pre-1933	2/3:40,000	UBC 3	21	8.7	
Chermoya Av.	Pre-1933	2:14,000	UBC 3	21	12.4	
Dorris Pl.	Pre-1933	2:20,000	UBC 3	21	9.7	
15th St.	Pre-1933	2:18,000	UBC 3	21	12.7	
59th St.	Pre-1933	2:17,000	UBC 3	21	16.5	
Malabar St.	Pre-1933	2/3:14,000	UBC 3	21	13.6	
99th St.	Pre-1933	2:18,000	UBC 3	21	10.9	
28th St.	Pre-1933	2:23,500	UBC 3	21	11.1	
Vernon City	Pre-1933	2:17,600	UBC 3	21	11.3	
Hammel St.	Pre-1933	2/3:30,900	UBC 3	21	11.7	
Peary	1932	1:14,900	UBC 3	21	13.6	

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
MASONRY BEARING WALLS WITH WOOD FLOORS AND ROOF-LA SCHOOLS						
Rosewood	1926	2:14,900	UBC 3	21	8.1	
Pacific Pal.	1931	2:20,600	UBC 3	21	10.9	
REINFORCED CONCRETE FRAME WITH MASONRY INFILL-VA						
Mt. Home-72	1935	3:14,700	0.10g	ok	-	r
Mt. Home-8	1933	3:48,100	.1g	5		j,n,u
Portland-1	1920's	6:47,300	UBC 2	12,8	42.5	
Portland-2	1928	3:20,00	UBC 2	12	27.8	
Portland-16	1932	3:N/A	UBC 2	N/A	N/A	
Portland-6	1928	3:16,000	UBC 2	12	40.1	
Portland-25	1949	7:100,00	UBC 2	ok	-	q
Birming-A	1971	2:28,400	0.11g	8	1.0	s
Birming-B	1965	4:30,000	0.11g	16	0.9	t
Birming-C	1952	9:493,000	0.11g	11,23	9.4	
Manchest-1	1950	6:175,000	0.12g	12,23	8.6	
Roseburg-2	1932	3:76,700	UBC 2	11,8	9.9	u
Roseburg-3	1932	3:12,300	UBC 2	11,8	8.4	u
Roseburg-1	1932	5:111,700	UBC 2	11,13,8	9.6	u
Roseburg-16	1935	2/1:18,000	UBC 2	11,13,8,7	11.1	g,h
Walla-86	1927	3:47,000	UBC 2	1,20	4.1	
Walla-80	1932	2:22,600	UBC 2	1,3,7	9.8	u
Marion-1	1930's	4/3:80,000	0.11g	12,8	33.5	
Marion-2	1930's	3:30,000	0.11g	12,8	32.2	

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
REINFORCED CONCRETE FRAME WITH MASONRY INFILL-VA						
American-81	1945	4:75,000	1.5xUBC 3	19,11,8,9	13.8	u
American-85	1947	4:40,000	1.5xUBC 3	1,11,8,9	13.3	u
Salt-1	1950's	7:201,000	UBC 3	19,3	7.2	
Salt-5	1950's	1:41,000	UBC 3	19	3.5	
Salt-3	1950's	3:77,300	UBC 3	19,3	6.1	
Salt-2	1950's	3:100,700	UBC 3	19,3	5.9	
Salt-8	1950's	1/2:52,200	UBC 3	19,3	5.3	
Salt-6	1950's	1:24,200	UBC 3	19,7	11.5	o,h
Salt-4	1950's	1:59,000	UBC 3	19	2.7	
Salt-9	1950's	1:12,900	UBC 3	19,3	11.9	g
Augusta-1	1921	2:14,700	0.18g	1	7.4	
Augusta-76	1945	2:67,600	.18g	11,2	N/A	
Seattle-1	1951	8:215,800	.20g	11,23	17.2	q
Harrison-141	1930's	3:51,100	.30g	11,2,10	1.9	n
Harrison-154	1962	4:110,600	0.30g	ok	-	
Memphis-1	1967	3/15:750,000	0.25g	11	12.0	t
REINFORCED CONCRETE FRAME WITH MASONRY INFILL-LA SCHOOLS						
Hamilton	1931	3:66,200	UBC 3	21	11.3	
REINFORCED CONCRETE BEARING WALLS WITH CONCRETE FLOORS AND ROOF-VA						
Seattle-8	1950's	2:7,300	UBC 3	ok	-	
American-62	1932	1:11,100	1.5xUBC 3	7	1.9	u

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
REINFORCED CONCRETE BEARING WALLS WITH CONCRETE FLOORS AND ROOF-VA						
August-15	1923	1:4,500	0.18g	ok	-	o,h
Prescott-32	1910	1:1,900	0.15	ok	-	u
Prescott-107	1937	4:93,700	0.15	ok	-	
Prescott-108	1939	2:12,500	0.15	ok	-	
Prescott-112	1957	2:17,300	0.15	ok	-	
Fresno-11	1947	1:4,100	0.23	6	1.7	1
Fresno-10	1947	1:8,700	0.23	6	2.8	1
Fresno-3	1947	1:8,00	0.23	7	3.0	
Fresno-2	1947	1:8,00	0.23	ok	-	o
REINFORCED CONCRETE BEARING WALLS WITH CONCRETE FLOORS AND ROOF-LA SCHOOLS						
Morningside	1916	2:32,000	UBC 3	21	7.9	u,v
Van Nuys	1933	2:20,500	UBC 3	21	8.1	
Mann	1926	2:109,000	UBC 3	21	5.1	
N. Holly-M	1927	2:64,200	UBC 3	21	7.5	u
54 Street	1927	2:37,200	UBC 3	21	8.5	u,v
N. Holly-S	1927	1:9,700	UBC 3	21	3.8	u
STEEL FRAME-VA						
Mt. Home-93	1939	2:27,00	0.10g	11,7	7.9	1,u
Roseburg-7	1932	1:6,000	UBC 2	ok	-	o
Atlanta-1	1966	12:468,000	0.13g	13	1.7	

Building Name[a]	Age[b]	Size[c]	Design level[d]	Reinforcing[f]	Cost[e]	Notes
		STEEL FRAME-VA				
Seattle-14	1972	2:28,400	0.20g	5,13	6.6	
Fresno-1	1947	7/9:247,600	0.23g	11	4.4	q
Harrison-142	1931	1:4,700	0.30	3,10,7	7.0	
		WOOD FRAME-VA				
Walla-1	1888	2:6,000	UBC 2	N/A	0.5	
Vancouver-A	1940	N/A:4,000	UBC 2	24	4.5	p
Vancouver-B	1940	N/A:4,000	UBC 2	24	4.0	p
Seattle-9	1950's	1:2,200	UBC 3	ok	-	
Seattle-6	1950's	1:6,400	UBC 3	ok	-	
Seattle-7	1950's	1:2,900	UBC 3	ok	-	
Prescott	1910	1:2,200	0.15g	ok	-	
Prescott	1920	1:4,800	0.15g	ok	-	
		WOOD FRAME-LA SCHOOLS				
Elysian	1917	1:3,600	UBC 3	21	9.2	w
Wadsworth	1925	1:9,300	UBC 3	21	5.0	
Vinedale	1925	1:3,600	UBC 3	21	10.3	w
Sylvan Pk.	1925	1:3,600	UBC 3	21	14.0	w

FOOTNOTES (for Table A-1)

a: names are arbitrary

b: date of construction of original building

c: number of floors: total floor area in square feet

d: UBC 2 Uniform Building Code, zone 2

UBC 3 Uniform Building Code, zone 3

0.10g ground acceleration a in Handbook H-08-8

e: cost of reinforcing in 1975 dollars per square foot; includes cost for repair of finishes, etc.

f: 1 - add gunite to all exterior walls

2 - add gunite to some exterior walls

3 - add new concrete block shear wall

4 - strengthen wood floor for diaphram loads

5 - tie wood floor to new and existing walls

6 - tie roof to walls

7 - strengthen roof for diaphram loads

8 - brace interior non-bracing partitions

9 - replace heavy roof material

10 - remove or strengthen cornice or parapets

11 - add new concrete shear wall, interior or exterior

12 - build towers adjacent to building for bracing

13 - add steel cross-bracing

14 - brace walls with steel trusses

f: 15 - replace wood floor with concrete floor

16 - cut expansion joint

17 - demolish

18 - add plywood shear wall

19 - replace outer layer of masonry with reinforced grout space and new masonry

20 - fill windows

21 - reinforce building to comply with Title 21 standards; all masonry walls receive gunite

22 - close expansion joint

23 - build new foundations under new shear walls

24 - brace masonry piers under building

g: this building is a theater

h: the walls or stories are particular high

i: building labled as 'historic'

j: building has concrete floors

k: former greenhouse

l: building has steel truss roof system

m: building has a tower

n: building has had previous earthquake strengthening

o: building is a boiler plant

p: average cost for many identical buildings q: original building designed for earthquake loads

r: original attic story of this 1903 building replaced by a light framed 3rd story in 1935

s: building has concrete core walls

t: building has exterior wall that are not fill-in masonry

u: building has wood roof

v: building has wood floor.

w: school assembly building

LIST OF PREVIOUS REPORTS

1. Whitman, Cornell, Vanmarcke, and Reed, "Methodology and Initial Damage Statistics", Department of Civil Engineering Research Report R72-17, Structures No. 339, March 1972.

2. Leslie and Biggs "Earthquake Code Evaluation and the Effect of Seismic Design on the Cost of Buildings", Dept. of C.E. R72-20, ST No. 341, May 1972.

3. Anagnostopoulos, "Non-linear Dynamic Response and Ductility Requirements of Building Structures Subject to Earthquakes", Dept. of C.E. R72-54, ST No. 349, September 1972.

4. Biggs and Grace, "Seismic Response of Buildings Designed by Code for Different Earthquake Intensities", Dept. of C.E. R73-7, ST No. 358, January 1973.

5. Czarnecki, "Earthquake Damage to Tall Buildings", Dept. of C.E. R73-8, ST No. 359, January 1973.

6. Trudeau, "The Shear Wave Velocity of Boston Blue Clay", Dept. of C.E. R73-12, SO No. 317, February 1973.

7. Whitman, Hong and Reed, "Damage Statistics for High-Rise Buildings in the Vicinity of the San Fernando Earthquake", Dept. of C.E. R73-24, ST No. 363, April 1973.

8. Whitman, "Damage Probability Matrices for Prototype Buildings", Dept. of C.E. R73-57, ST No. 380, November 1973.

9. Whitman, Biggs, Brennan, Cornell, de Neufville, and Vanmarcke, "Summary of Methodology and Pilot Application" Dept. of C.E. R73-58, ST No. 381, October, 1975.

10. Whitman, Biggs, Brennan, Cornell, de Neufville and Vanmarcke, Methodology and Pilot Application", Dept. of C.E. R74-15, ST No. 395, July 1974.

11. Cornell and Merz, "A Seismic Risk Analysis of Boston", Dept. of C.E. Professional Paper P74-2, ST No. 392, April 1974.

12. Isbell and Biggs, "Ineslastic Design of Building Frames to Resist Earthquakes", Dept. of C.E. R74-36, ST No. 393, May 1974.

13. Ackroyd and Biggs, " The Formulation and Experimental Verification of Multistory Buildings", Dept. of C.E. R74-37, ST No. 394, May 1974.

14. Taleb-Agha, "Sensitivity Analyses and Graphical Methods for Preliminary Solutions", Dept. of C.E. R74-41, ST No. 403, June 1974.

15. Panoussis, "Seismic Reliability of Infinite Networks", Dept. of C.E. R74-57, ST No. 401, Sept 1974.

16. Whitman, Yegian, Christian and Tezian, "Ground Motion Amplification Studies, Bursa Turkey", Dept. of C.E. R74-58, ST No. 402, September 1974.

17. de Neufville, "How do we Evaluate and Choose Between Alternative Codes for Design and Performance", in preparation.

18. Tong, "Seismic Risk Analysis for Two Sites Case", Dept. of C.E. R75-23, Order No. 504, May 1975.

19. Wong, "Correlation Between Earthquake Damage and Strong Ground Motion", Dept. of C.E. R75-24, Order No. 505, May 1975.

20. Munroe and Blair, "Economic Impact in Seismic Design Decision Analysis", Dept. of C.E. R75-25, Order No. 506, June 1975.

21. Veneziano, "Probabalistic and Statistical Models for Seismic Risk Analysis, Dept. of C.E. R75-34, Order No. 513, July, 1975

22. Taleb-Agha, "Sesimic Risk Analysis of Networks", Dept. of C.E. R75-43, Order No. 519, September 1975

23. Taleb-Agha, Whitman, "Seismic Risk Analysis of Discrete Systems", Dept. of C.E. R75-48, Order No. 523, December 1975.

24. Taleb-Agha, "Seismic Risk Analysis of Lifeline Networks, Dept. of C.E. R75-49, Order No. 524, December 1975.

25. Unemori, "Nonlinear Inelastic Dynamic Analysis with Soil-Flexibility in Rocking", Dept of C.E. R76-13, Order No. 532, February 1976.

26. Yegian, "Risk Analysis for Earthquake-Induced Ground Failure by Liquefaction" Dept. of C.E. R76-22 Order No. 542, May 1976.

27. Hein, Whitman, "Effects of Earthquakes on System Performance of Water Lifelines", Dept. of C.E. R76-23, Order No. 544, May 1976.

28. Larrabee, Whitman, "Costs of Reinforcing Existing Buildings and Constructine New Buildings to Meet Earthquake Codes", Dept. of C.E. R76-25, Order No. 546, June 1976.