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7/25/68

**BUILDING FAILURES DUE TO LIVE LOADS**

**A THESIS**

**Presented to**

**The Faculty of the Division of Graduate  
Studies and Research**

**by**  
*Callahan*  
**Henry C. Parrish, III**

**In Partial Fulfillment**

**of the Requirements for the Degree  
Master of Science in Civil Engineering**

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BUILDING FAILURES DUE TO LIVE LOADS

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## NOMENCLATURE

| Symbol                   |   |
|--------------------------|---|
| Y                        | Random variable representing the area of a live load failure          |
| $\ln Y$                  | Natural logarithm of Y ( $\log_e Y$ )                                 |
| e                        | 2.71828   |
| X                        | Normally-distributed random variable representing $\ln Y$             |
| $f_Y(y)$                 | Probability density function for the area of a live load failure      |
| $\exp(s)$                | $e^s$   |
| $\sigma$                 | Standard deviation of X ( $\ln Y$ )                                   |
| $\mu$                    | Mean of X ( $\ln Y$ )   |
| A                        | Average number of unreported live load accidents                      |
| $CRC_{40}$               | Capital recovery cost of structure designed for a live load of 40 psf |
| U                        | Random variable representing live floor load values                   |
| $F_U(80\text{psf})$      | Probability that U will be less than or equal to 80 psf               |
| $F[U \geq 80\text{psf}]$ | Probability that U will be greater than or equal to 80 psf            |
| $FR_{30}$                | Estimated failure rate for an office building designed at 30 psf      |
| n                        | Number of loading arrangements  |
| $\bar{x}$                | Sample mean   |
| $S^2$                    | Sample variance   |

## SUMMARY

Structural design today consists of satisfying deterministically stated code requirements, with (it is hoped) the achievement of a low cost, safe structure. These code requirements consist of maximum stresses which cannot be exceeded when stated minimum loads are applied. However, structural failures due to, for example, floor live loads, occur frequently. It is of interest to determine the actual probability of structural failure due to live loads.

A first step is to determine the observed probability of such failures. This thesis determines this observed probability, by analyzing structural failures as reported in a news medium. Ancillary studies are also reported.

## CHAPTER I

### INTRODUCTION

Present-day structural design practice consists of satisfying deterministically stated code requirements, hopefully achieving a low-cost, safe structure. These code requirements consist of maximum stresses which must not be exceeded when the stated minimum loads are applied. However, failures due to overloading occur causing extensive personal and property damage. These accidents imply that structures are subjected to loads far in excess of their resistances, and the purpose of this paper is to investigate the rate of occurrence of these accidents.

#### Code Valuations of Live Loads

Floors in all buildings are designed and constructed for "maximum" loads that have been assumed to be produced by various types of occupancy. These loads per square foot of area are also assumed to be uniformly distributed, and are listed accordingly in all codes. A section of live-load specifications taken from the 1967 National Building Code can be seen in Table 1.

These live-load values sometimes vary among different building codes. Moreover, definitions of live load may also vary among codes. Most United States building codes consider live loads as those weights superimposed by use or occupancy of the building (1). The typical code in the United States excludes wind, snow, earthquake, and dead loads from

Table 1. Section of Live Loads Specified in the 1967 National Building Code (United States)

| Occupancy  | Live Load<br>Lbs. per sq. ft. |
|--|-------------------------------|
| <b>Assembly:</b>   |                               |
| Armories and drill rooms   | 150                           |
| Assembly halls, auditoriums, churches,<br>lecture halls, lodge rooms and similar<br>assembly occupancies |                               |
| Fixed seats  | 60                            |
| Movable seats  | 100                           |
| Bowling lanes, poolrooms and similar<br>recreational areas   | 75                            |
| <b>Business:</b>   |                               |
| Offices  | 80                            |
| Letter file rooms  | 80                            |
| Card file rooms  | 125                           |
| <b>Educational:</b>  |                               |
| Libraries:   |                               |
| Corridors  | 100                           |
| Reading rooms  | 60                            |
| Stack rooms  | 150                           |
| Schools and Colleges:  |                               |
| Class rooms  | 40                            |
| Corridors  | 100                           |
| <b>Industrial:</b>   |                               |
| Bakery   | 150                           |
| Factories and manufacturing plants   | 125                           |
| Foundries  | 600                           |
| Ice manufacture  | 300                           |

live floor loadings. Canada, on the other hand, in its National Building Code includes snow, rain, movable partitions, vertical loads due to cranes, and hydrostatic pressure as live loads, excluding permanent partitions, equipment, ductwork, and piping. As a result, live-load design values may differ widely between localities.

Design live loads also vary because of reductions allowed due to contributory areas. It has long been recognized that live-load intensities are relevant to only a particular structural element under study (1). As a result, a reduction in load intensity is allowed for large contributory areas. These reductions are usually area-dependent, such as the cumulative number of floors being supported by a column. These load reductions also depend on the type of occupancy. Warehouses, assembly rooms, and parking garages may have restrictions requiring a larger contributory area, using a lesser reduction rate, or imposing a maximum permissible reduction.

Code variances and contributory area effects will influence the determination of design live loads. Consequently, most structures designed today will differ greatly in their design loads even though they are of the same type of occupancy.

#### Actual Live Loads

Actual live loads cannot really be specified as existing codes have done. They are ever-changing, time-dependent values. Live loads are invariably movable objects which may undergo constant relocation. Furniture, fixtures, and filing cabinets may be rearranged often. People are constantly moving through buildings applying uncertain loadings at

any point in time. Assemblies, fire drills, and parties will have a great effect on the loadings encountered in a structure. Additional live loads may be applied as a result of tenancy changes. New tenants will tend to change the total loading and loading arrangements. However, this may not always be the case. Executives will usually occupy window offices, filing cabinets are placed on interior walls, and secretarial departments are frequently located in the middle. Consequently, it is possible for little change to occur between tenancy changes.

It is as difficult to estimate the loads on a structure during its lifetime as it is to determine the resistance of the structure. Therefore, studies of these qualities suggest probabilistic analysis.

#### Remarks

Existing code values for live loads have been generally assumed to represent a conservative estimate of maximum loads. Little work has been done on this subject until recently. Previously, it was felt that the results of actually measuring the loads were not worth the expense and trouble involved, and, in addition, that there was no real need because of the few cases of building collapse due to incorrect load assumptions. The latter suggests that today's structures are currently being overdesigned. Studies have been conducted by the National Bureau of Standards and the Department of Commerce, and in most cases the actual average floor load was far less than the stated code design loads.

It appears that in the future more attention should be paid to economic analysis and optimum designs, a procedure prohibited in present-day codes. A first step towards this type of code would be the

determination of the actual probability of live-load failures under today's codes.

To determine an observed failure rate which could be used to estimate the actual failure rate, the author investigated two sources. First, a thorough study of insurance company records was conducted in order to determine the feasibility of such an approach. As a result, a company dealing in professional liability insurance for engineers was used as a source for data, which are presented in Chapter II. A second source, discussed in Chapter III, is based on an analysis of a news magazine's stories on structural failures. Finally, an analytical procedure for determining the optimum design based on economic considerations is introduced.

## CHAPTER II

### ACCIDENT DATA FROM INSURANCE COMPANIES

Insurance companies deal with failures firsthand and are a logical source of accident data. It is their responsibility to investigate, defend their case, and pay damages for all types of structural failures. Consequently, a large amount of information would be available in their files. It must be remembered, however, that any data obtained from this source would be biased; i.e., not truly representative of the population as a whole. There are three groups that would make up this total population:

1. Those people who desire insurance and are accepted,
2. Those people who desire insurance but are not accepted, and
3. Those people who do not want insurance.

Any data obtained from insurance companies would be based solely on a sample of group 1. Groups 2 and 3 would be excluded from these data and must be accounted for before any final conclusions are made.

The majority of insurance companies dealing with structures underwrite fire, wind, and rain accidents. Only one was found to have a professional liability insurance program for engineers: Victor O. Schinnerer and Company, Inc., of Washington, D. C. This company has been insurance counselor to both the American Institute of Architects and the National Society of Professional Engineers for fifteen years. The company is also a consultant to the AIA and NSPE-PEPP Contract

Documents Review Committees and insurance counselor to the American Congress on Surveying and Mapping and the American Society of Landscape Architects. It also underwrites professional liability policies which are carried by Continental Casualty Company, a member company of CNA/Insurance. At one time a total of nine different companies were engaged in the field of professional liability insurance. Schinnerer and Company has remained as the only such nationwide concern.

Presently, about 10,000 firms are insured in the Schinnerer program. Since the beginning of the program in 1956, over 11,000 claims have been handled with about 3,300 still pending (2). New claims are being reported at about 150 per month. The present Schinnerer program is now running at a loss ratio of 101.22% with an incurred loss of \$72,697,689. Incurred loss is the sum of the total money spent on claims plus the reserve for future settlements, and the loss ratio is the ratio of the incurred loss to the total premiums paid. Over the past fourteen years, CNA has lost about nine million dollars on the program.

A visit with officials at Victor O. Schinnerer, Inc. produced the data in Appendix C, consisting of a summary of the nationwide program results for various engineering classifications during the years 1956-1971. A random sampling of six Georgia structural engineers is also included. Unfortunately, no breakdown of live-load failure data was readily available. Although such failures were reported in their files, there was no reasonable method of sorting them out.

The future for Victor O. Schinnerer and Company, Inc. as a source for all types of failure data looks bright. A computer classification system has recently been set up in order to organize the various types

of structural accidents. Since the normal case requires about five years before complete settlement, it will take at least that long before the data begin to accumulate.

## CHAPTER III

## ACCIDENT DATA FROM NEWS MEDIA

Not all structural accidents are widely reported in the news media. Those which are reported are of greater public interest than those which are not; the reported accidents tend to have more deaths and injuries associated with them and perhaps are of larger magnitude. In a preliminary survey of reported structural accidents, it was determined that Engineering News-Record contained more such reports than any other widely available publication. A study was made of all failures, due to widely varying causes, which were reported in Engineering News-Record during the ten-year period 1962-1971. Out of a total of 84 failures that occurred during this period, only eleven were due to excessive live loads being placed on the structure. The majority of these failures took place while the structure was still under construction. Nine of the eleven reported failures occurred in the United States.

Description of Live-Load FailuresUnited States Failures.

Dearborn, Michigan. One unit of a sixty-unit motel collapsed while being load tested. Cracked precast concrete beams had been noticed throughout the motel shortly after its completion. A portion of the roof of the two-story building failed during the test causing two deaths. The area of the accident was estimated at 600 square feet. (March, 1963).

Ocala, Florida. A concrete roof canopy extending along one wall of a courthouse collapsed while under construction. Three errors were cited in the accident:

1. Top reinforcing bars were placed too deep in the cantilevered slab,
2. Some bars were not anchored to the spandrel beams, and
3. The canopy was loaded with about two tons of roofing material.

An estimated 500 square feet failed. (September, 1963).

Merritt Island, Florida. Formwork for a third-floor slab of the Saturn rocket Vertical Assembly Building collapsed when a bundle of reinforcing bars was lowered onto it by a crane. The forms and supporting bar joists crashed through the formwork for the second story of the steel-frame building. Five people were injured, and the failure was estimated at about 30,000 square feet. (June, 1964).

Jacksonville, Florida. Formwork collapsed during the early stages of erection injuring two people. The cause of the collapse in the four-story addition to a church was attributed to overloading of the shoring with large metal pans. An estimated 1600 square feet of the roof deck failed. (May, 1965).

New York, New York. A floor failure of a 103-year-old factory building occupied by a plastics firm occurred when it was overloaded. Large manufacturing equipment had caused the floor to be loaded to four times its estimated capacity. Sections of the fifth, fourth, and third floors caved in, injuring twelve people. The total failure was estimated at 6900 square feet. (February, 1966).

Dallas, Texas. A 139-foot section of a second-story reinforced

concrete cantilever at the Dallas Trade Mart collapsed during construction. The design of the four-story building (960,000 square feet) proved to be acceptable, and the cause of the failure was attributed to excessive floor loading. Damage was estimated at \$50,000 or about 3800 square feet. (May, 1966).

New York, New York. A partial collapse of the sixteenth floor in a 42-story building under construction was caused when excessive steel was stored on that floor. A total of four bays failed in this concrete-core, steel-framed building. About 2600 square feet were estimated to have failed. (September, 1968).

Pittsburgh, Pennsylvania. An eight-by-twenty-foot section of nine floors collapsed in a 20-story apartment under construction, killing two pedestrians. Masonry block stored on the nineteenth floor overloaded the concrete plank flooring. The failure area was estimated at 1,440 square feet. (March, 1970).

Boston, Massachusetts. Half of a sixteen-story luxury apartment collapsed while under construction. The roof of the steel-framed building failed first, after it had been concreted. The entire wing followed. Four workmen were killed. The failure appeared to have three possible causes:

1. Formwork collapse,
2. Heavy piece of equipment dropped on the roof, or
3. The concrete had been placed during intense cold weather.

The estimated failure area was 111,000 square feet. (January, 1971).

Summary. The data for the above failures are presented in Table 2. Table 2 indicates that over the past ten years a total area of

Table 2. Live Load Failures in U. S. 1962-1971

| Size<br>(Sq. Ft.) | Year  | Location                  |
|-------------------|-------|---------------------------|
| 600               | 1963  | Dearborn, Michigan        |
| 500               | 1963  | *Ocala, Florida           |
| 30,000            | 1964  | *Merritt Island, Florida  |
| 1,600             | 1965  | *Jacksonville, Florida    |
| 6,900             | 1966  | New York, New York        |
| 3,800             | 1966  | Dallas, Texas             |
| 2,600             | 1968  | *New York, New York       |
| 1,440             | 1970  | *Pittsburgh, Pennsylvania |
| 111,000           | 1971  | *Boston, Massachusetts    |
| 158,440           | Total |                           |

\* Building was under construction at the time of the failure.

158,440 square feet was reported as failing due to live loads. Furthermore, out of nine accidents, six occurred during construction, amounting to 147,140 square feet.

#### Foreign Failures.

The remaining two live-load failures reported in Engineering News-Record during this ten-year period occurred in Spain. One accident took place in Madrid at a three-day-old two-story restaurant. The upper floor failed during a convention, killing fifty-three people. Construction of the structure was rushed, and reports said that some of the poured concrete was not cured. One source reported that the hall was filled with more people than it could hold.

At Malaga, Spain, four people were killed and twelve injured when the roof slab on an annex to a nine-year-old hotel collapsed. The reinforced concrete slab was in the process of being converted from flower gardens to tennis courts. Heavy machinery which overloaded the roof caused the accident.

#### Analysis of Reported Live-Load Failures

To permit further analysis, various types of probability density functions (PDF) were tested for suitability; the random variable (RV) was the area of the failure. Since a negative failure area was meaningless, the chosen PDF could not permit negative values of the random variable. One such distribution which had this characteristic was the lognormal.

While the normal distribution represents the sum of many small effects, the lognormal is based on the multiplication of a large number of variables. It has a long history in civil engineering since its

first use in 1914 by Hazen in statistical studies of hydrological data (3). Since then, the lognormal has seen a variety of applications ranging from the growth of certain economic systems to the crushing of aggregates and the transport of sediments in streams.

Letting  $Y$  be the random variable for the size of live-load failures and using the lognormal distribution, we expect  $\ln Y$  to be normally distributed. Consequently,  $Y = e^X$ ,  $X$  being a normally-distributed variable. The PDF of  $Y$  would be of the form

$$f_Y(y) = \frac{1}{y\sqrt{2\pi}\sigma} \exp\left\{-\frac{1}{2}\left[\frac{1}{\sigma} \ln(y/\mu)\right]^2\right\}$$

where  $\sigma$  and  $\mu$  are the parameters.

The lognormal is especially useful in our study because of its skewed quality allowing it to fit the observed data after a simple transformation of the familiar normal distribution. The distribution for the size of live-load accidents is skewed to the left placing more emphasis on the smaller failures. There are many more occurrences of small failures than of total building collapses. A construction worker overloading a small floor area with concrete block or other materials is a frequent happening on many sites. This type of accident has a high rate of occurrence, although it may go unreported because of its insignificance. Consequently, the skewed nature and the non-negative characteristics of the lognormal make it the most suitable distribution for further calculations on the area of floor failure.

### Unreported Data.

News magazines cannot possibly cover all failures that have occurred. Their sources are limited, and the stories must be interesting. There are three types of failures that have a good chance of being reported:

1. Extremely large failures,
2. Failures causing loss of life or a large amount of property damage, and
3. Failures occurring under unusual circumstances such as excess snow loads, new designs that are being tested, or new methods of construction.

Small failures will have little probability of being reported. Other failures will be unreported because Engineering News-Record does not hear of them. One such live-load failure occurred in Atlanta. A number of apartments collapsed when sheetrock was stored in vertically aligned living rooms. Although coverage was provided in the local news media, Engineering News-Record made no mention of the accident.

It is evident that the reported data do not give a true picture of the distribution of the size of accidents. A new distribution must be determined so that the unreported data will be included. To accomplish this, a transfer function was developed under the following assumptions:

1. There is a 10% chance of reporting failures of 100 square feet or less, and
2. There is a 100% probability of reporting failures larger than 10,000 square feet.

This function is represented in Figure 1.

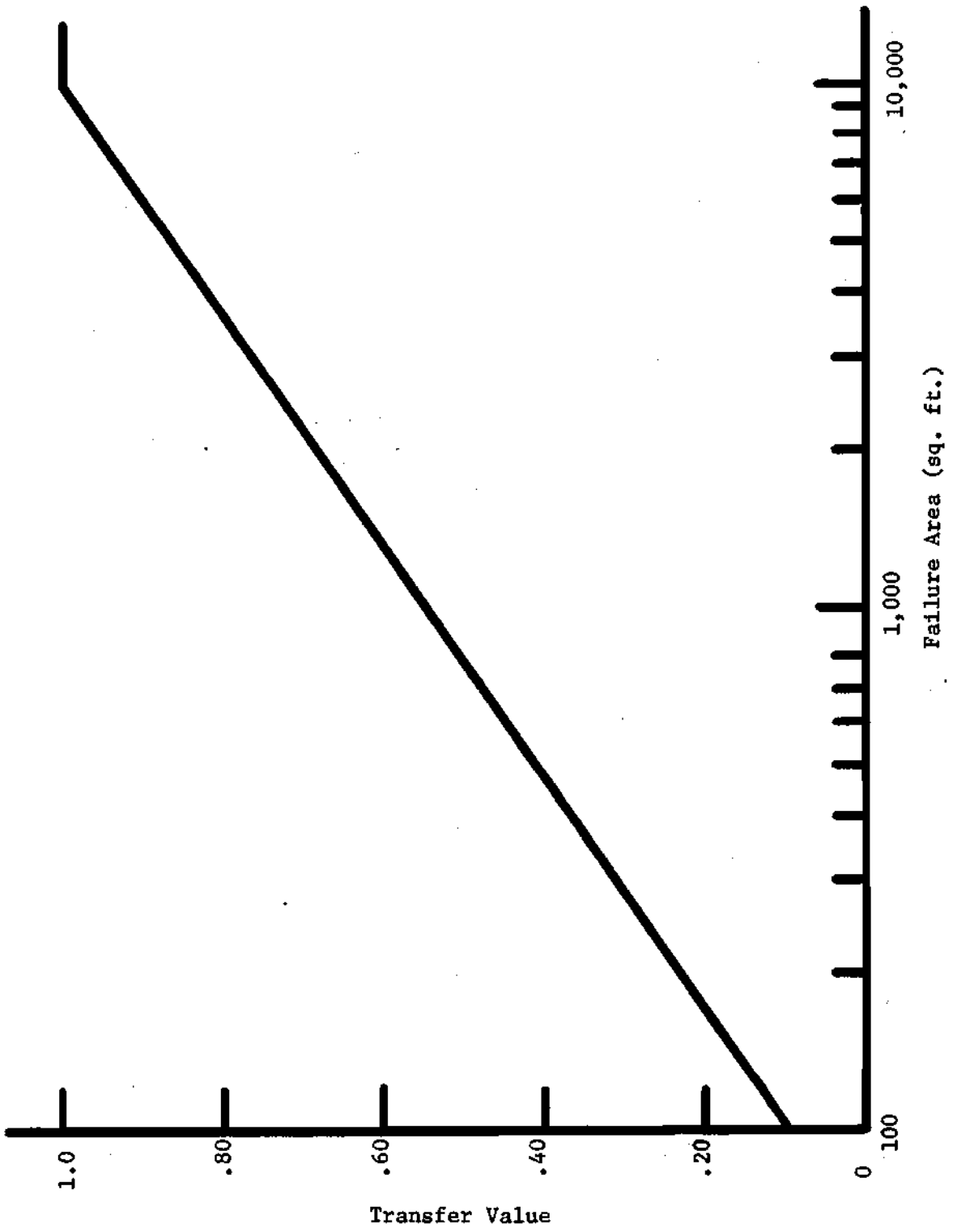


Figure 1. Transfer Function

The distribution to be transferred will only be a partial one. Failures of 10,000 square feet or larger are assumed to have a 100% change of being reported. Since these data will not be affected, they can be eliminated from the analysis. Instead, the transferred distribution would consist of all failures less than 10,000 square feet as seen in Table 3. In Table 3, the data for accidents of less than 10,000 square feet have been used to determine the mean (7.4581) and the standard deviation (.8784) of its PDF, the lognormal distribution.

The distribution in Table 3 can be transferred by a numerical analysis technique. The distribution is broken down into a number of intervals as can be seen in Table 4. The probability for each interval is then computed using a lognormal PDF. Using the midpoint of the interval, the transfer function in Figure 1 is evaluated. This value is then divided into the calculated probability for that interval. Now we have an unnormalized probability distribution. The sum of the probabilities for all the intervals is not one but is greater than one (1.69). Therefore each probability must be divided by this number to obtain a normalized probability density function. Figure 2 represents the transferred PDF plotted on the ln scale, and Figure 3 is the same PDF plotted on the arithmetic scale. This new PDF is composed of both reported data and the estimated unreported data.

Looking at Figure 2, one sees that the mean for all accidents less than 10,000 square feet is 1,500 square feet. Using this figure, one can estimate the number of unreported live-load accidents.

A total of 17,440 square feet of live-load failures less than 10,000 square feet was reported. There were seven reported failures in

Table 3. PDF of Reported Accidents of Less than 10,000 Square Feet

| Size<br>(Sq. Ft.) | ln Size                             |
|-------------------|-------------------------------------|
| 600               | 6.3969                              |
| 500               | 6.2146                              |
| 1,600             | 7.3777                              |
| 6,900             | 8.8393                              |
| 3,800             | 8.2427                              |
| 2,600             | 7.8633                              |
| 1,440             | 7.2724                              |
|                   | $\bar{X} = 7.4581$ (Antilog 1733.9) |
|                   | $s^2 = 0.7715$                      |
|                   | $s = 0.8784$                        |

Table 4. Transferring the PDF.

| Size of Accident Interval | Reported Probability (using log-normal PDF) | Transfer Value at Midpoint | Unnormal Transferred Probability | Normal Transferred Probability |
|---------------------------|---|----------------------------|----------------------------------|--------------------------------|
| 0 to 100                  | .00   | .10                        | .00                              | .00                            |
| 100 to 200                | .01   | .18                        | .06                              | .04                            |
| 200 to 300                | .01   | .28                        | .04                              | .02                            |
| 300 to 400                | .03   | .34                        | .09                              | .05                            |
| 400 to 500                | .03   | .38                        | .08                              | .05                            |
| 500 to 600                | .03   | .42                        | .07                              | .03                            |
| 600 to 700                | .04   | .46                        | .09                              | .05                            |
| 700 to 800                | .04   | .48                        | .08                              | .05                            |
| 800 to 900                | .04   | .51                        | .08                              | .05                            |
| 900 to 1,000              | .03   | .53                        | .06                              | .04                            |
| 1,000 to 2,000            | .30   | .62                        | .48                              | .28                            |
| 2,000 to 3,000            | .17   | .72                        | .24                              | .14                            |
| 3,000 to 4,000            | .10   | .80                        | .13                              | .08                            |
| 4,000 to 5,000            | .06   | .84                        | .07                              | .03                            |
| 5,000 to 7,000            | .05   | .90                        | .06                              | .04                            |
| 7,000 to 9,000            | .03   | .96                        | .03                              | .02                            |
| 9,000 to 10,000           | .01   | .99                        | .01                              | .01                            |
| 10,000 to 15,000          | .01   | 1.00                       | .01                              | .01                            |
| 15,000 and above          | .01   | 1.00                       | .01                              | .01                            |
|                           | <u>1.00</u>                                 |                            | <u>1.69</u>                      | <u>1.00</u>                    |

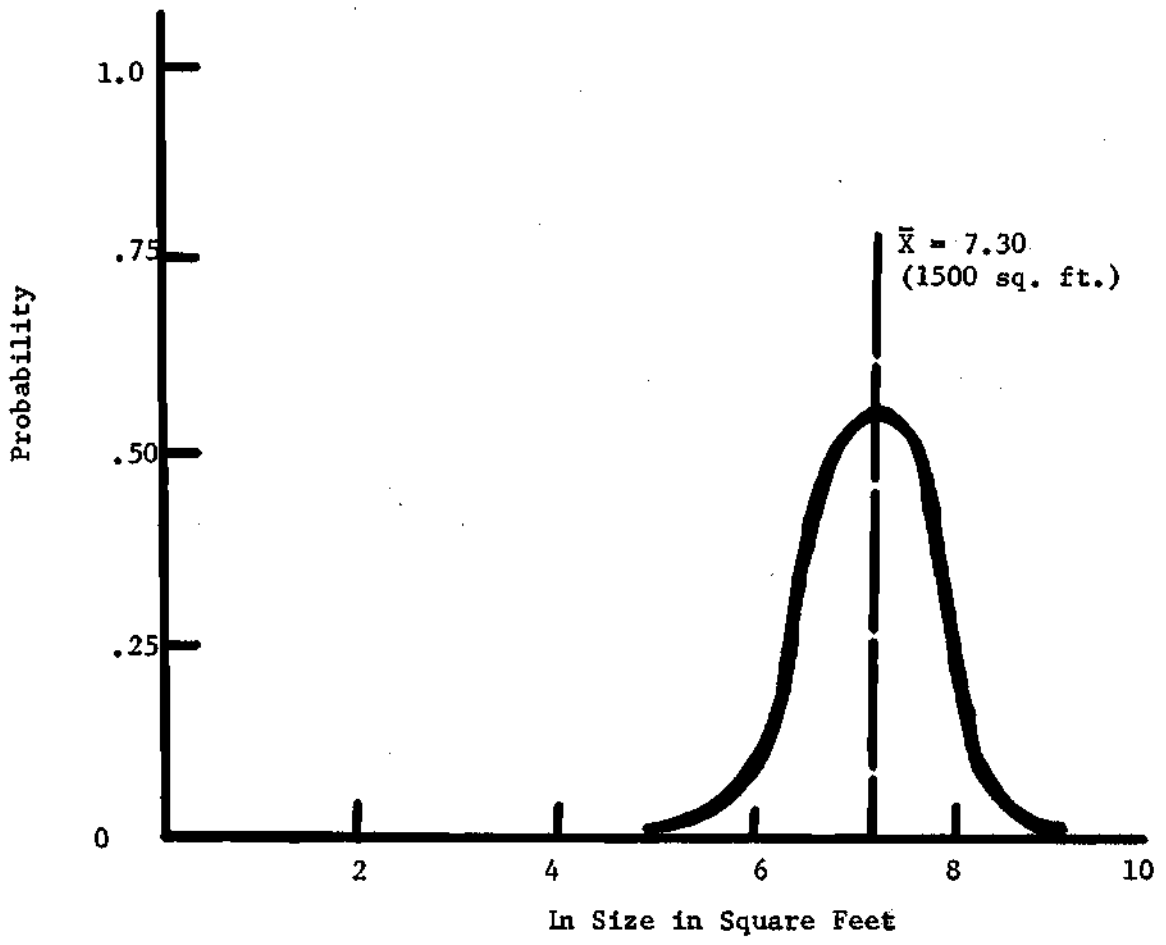


Figure 2. Estimated PDF for Failure Size on Ln Scale.

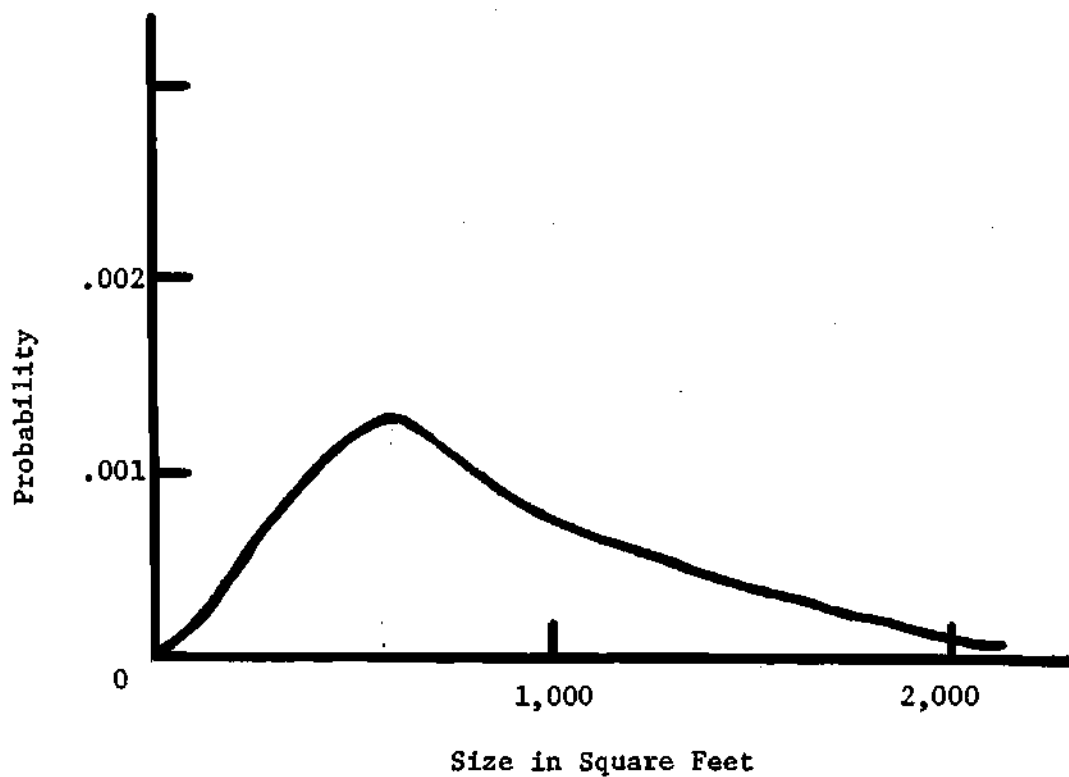


Figure 3. Estimated PDF for Failure Size on Arithmetic Scale

this class. In order to determine the amount of unreported data one needs to estimate an average size for unreported accidents. We know that this mean is slightly less than 1,500 square feet because unreported accidents will place an emphasis on the smaller accidents. Our study will assume 1,200 square feet as this mean. The average number of unreported accidents, A, can then be found by,

$$\frac{\text{Total Square Feet Failed}}{\text{Number of Failures}} = \text{Mean,}$$

the numerator being the sum of reported and unreported data. Substituting we have,

$$\frac{17,400 + 1,200A}{7 + A} = 1,500$$

$$A = 23.$$

Approximately twenty-three live-load failures of a mean size of 1,200 square feet apparently went unreported. Therefore, a total of

$$23 \times 1,200 = 27,600 \text{ square feet}$$

of live-load floor failures were not reported in Engineering News-Record.  
Probability of Failure Calculations.

The total reported live-load failure area is 158,440 square feet. Adding 27,600 square feet for unreported failures yields 186,040 square feet as the total amount of live-load failures.

From Construction Review yearly estimates of construction put in place were used to determine the total building population. Assuming an average building life of thirty years, a total population of  $72 \times 10^9$  square feet can be computed as seen in Appendix A. Consequently, the probability of failure due to live load is

$$\begin{aligned} \text{Probability of} \\ \text{failure due to} \\ \text{live load} &= \frac{186,040 \text{ sq. ft./10 years}}{72 \times 10^9 \text{ sq. ft.}} \\ &= 2.6 \times 10^{-7} \text{ sq. ft./sq. ft./year} \end{aligned}$$

A probability can also be computed for construction failures. Ninety-three percent (147,140 square feet) of all reported failures in the past ten years occurred during construction. Assuming this ratio remains the same for unreported data, we can estimate the unreported construction failures at

$$0.93 \times 27,600 = 25,668 \text{ square feet.}$$

The total amount of live load failures occurring during construction is

$$147,140 + 25,668 = 172,808 \text{ square feet.}$$

The total population for construction failures would be based on the number of square feet put in place by the construction industry each year. An average value can be determined by dividing thirty years into  $72 \times 10^9$  square feet. Therefore the construction probability of live-load failure, assuming one year for construction completion, would be,

$$\begin{aligned} \text{Probability of} & \\ \text{construction live} & = \frac{(172,808 \text{ sq. ft./10 years})(1 \text{ year})}{72 \times 10^9 \text{ sq. ft./30 years}} \\ \text{load failure} & \\ & = 7.2 \times 10^{-6} \text{ sq. ft./sq. ft./year.} \end{aligned}$$

## CHAPTER IV

## BENEFIT-COST ANALYSIS

Benefit-cost analyses are becoming commonplace in engineering studies. They are especially useful when determining the increments of benefit and cost related to a design change. For example, increasing the weight of a steel beam, and hence its cost, will bring a benefit in the form of decreased probability of failure. The optimum weight of the beam is approached when the incremental benefit of a design change, less the incremental cost of the design change, is positive. Ideally, the beam should be designed for this weight.

Universal Design Curve

It is not apparent that structures, when designed in conformance with present-day code provisions, are near the optimum on a benefit-cost basis. Figure 4 depicts cost and benefit variation as a function of a design parameter. This curve was originally developed for use in spillway design (4), but it can be applied to other problems. The optimum value for any parameter, e.g., design live floor load, can be determined by analyzing the benefits and costs for various parameter values. Plotting these values will result in curves very similar to those pictured in Figure 4. Point A on the curve probably represents a structure designed according to applicable present-day code provisions. It is an oversized structure which may be considered "safe" but is, economically speaking, wasteful. Point B represents a structure designed at the

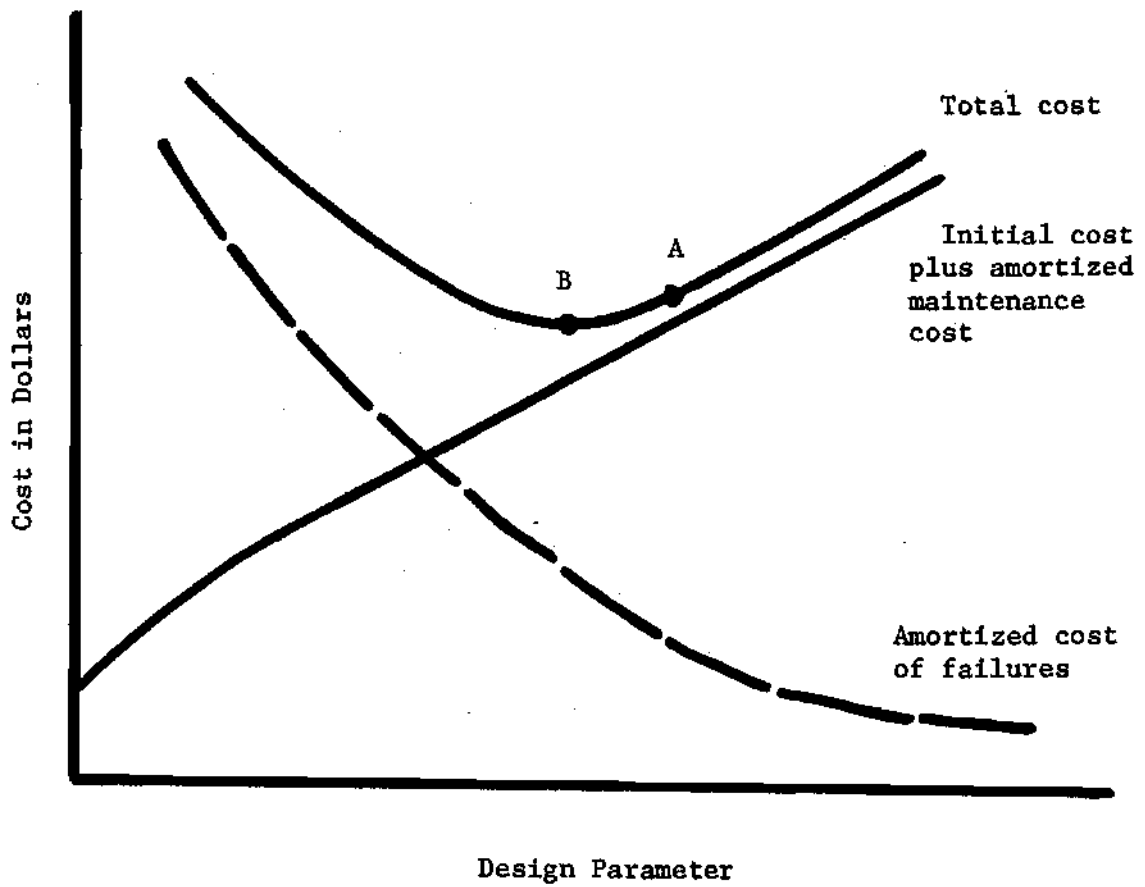


Figure 4. Cost and Benefit Variation As a Function of a Design Parameter

optimum. Although an increased failure rate will result, the decrease in costs will offset the loss making this the most economical approach.

#### Example Benefit Cost Analysis

Analyzing a particular design project will illustrate this point. A project to construct an office building will cost \$250,000,000 when designed by present codes. By reducing the design live load from 40 psf to 30 psf, first costs will be cut by, perhaps, 10%, yielding a cost of \$225,000,000. Assuming an annual interest rate of ten percent and a building life of thirty years, the capital recovery for each design can be determined by multiplying the first cost by the capital recovery factor.

$$CRC_{40} = \$250,000,000 \times .106 = \$26,500,000/\text{Year}$$

$$CRC_{30} = \$225,000,000 \times .106 = \$23,850,000/\text{Year}$$

The total yearly costs for these designs can be obtained by adding the capital recovery costs and the yearly maintenance costs.

Benefits will accrue to the owner through rental receipts or rental savings by actually using the structure himself. Reducing the design live floor load, as in the 30 psf design, will probably result in lower benefits for the owner. Such a structure because of its reduced load capacity would be less versatile and adaptable, restricting its possible future uses.

Negative benefits will result from floor failures that might occur during the life of the structure. Buildings designed by present codes

have an apparent failure rate of  $2.6 \cdot 10^{-7}$  sq. ft./sq. ft./year. Using the data in Figure 5, taken from live-load studies conducted by the National Bureau of Standards, a failure rate for the reduced design load of 30 psf can be estimated.

The data represented in Figure 5 are from a survey of loadings taken in the National Bureau of Standards administration office building. These data, however, represent only a single loading. During the life-time of a structure a number of loadings may be applied through tenancy changes, internal reorganization, or construction. Consequently, the important distribution is not the one shown in Figure 5 but rather a maximum value distribution which is a function of the number of loadings. Success or failure of a structure depends upon its ability to function under maximum loads, not simply typical values.

Heaney (1) has analyzed the distribution of maximum values for the National Bureau of Standards data, and it is depicted in Figure 6. The maximum value distributions have been computed for a number of loading rearrangements,  $n$ . Heaney determined that for values above  $n = 10$  there is not much effect on the distribution. In additional studies by Mitchell and Woodgate (5) the minimum tenancy duration averaged around 8.8 years. Assuming a building tenancy life of 100 years, Heaney estimates the number of occupancy changes during the life of a normal structure at eleven. When internal office rearrangements and construction loadings are included in this figure, the total number of loading rearrangements might range between 15 and 20. Heaney has analyzed the data for 16 loading rearrangements which is in our estimated range of 15 to 20, and since there is not much variation in the maximum loading distribution for

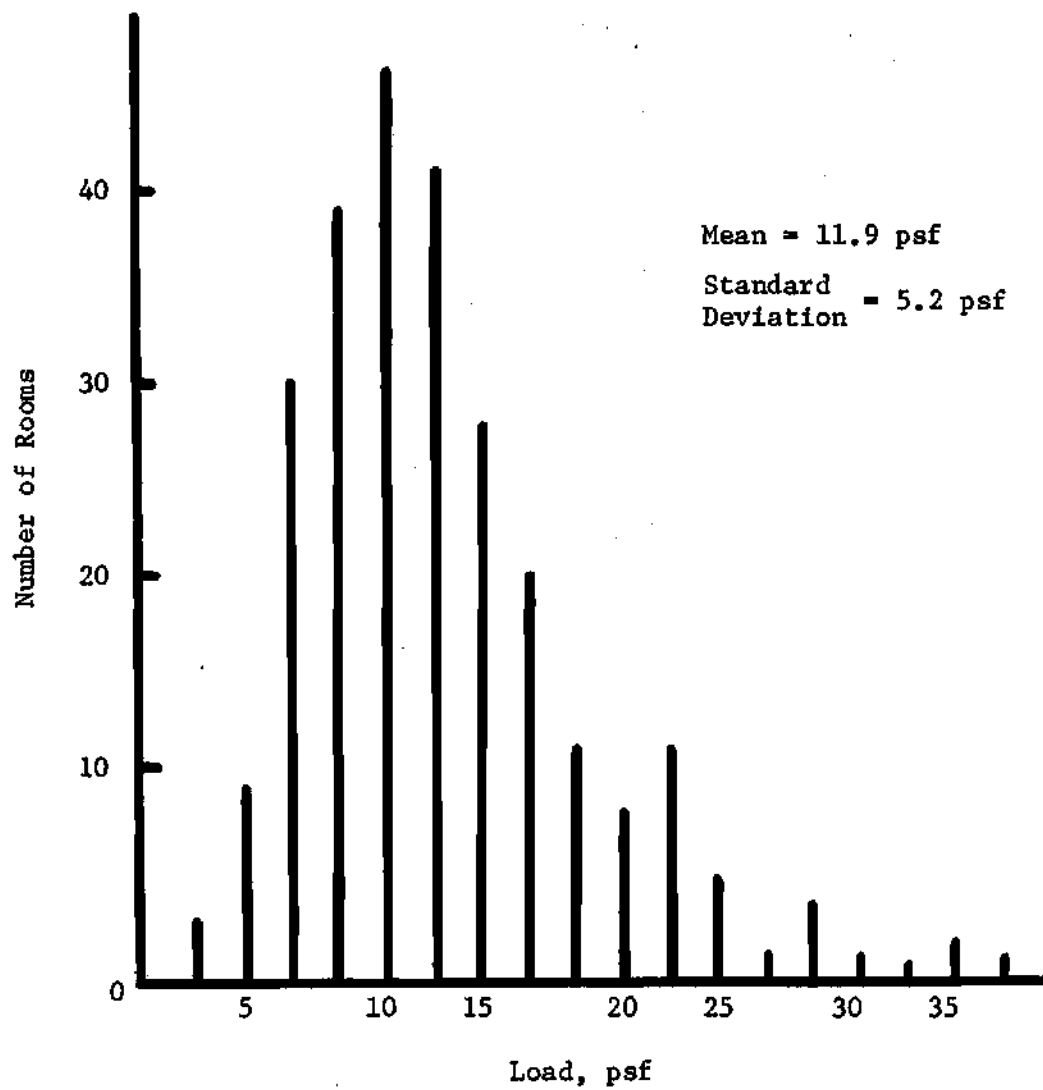


Figure 5. Frequency Distribution for Uniformly Distributed Loads in Office Rooms, National Bureau of Standards.

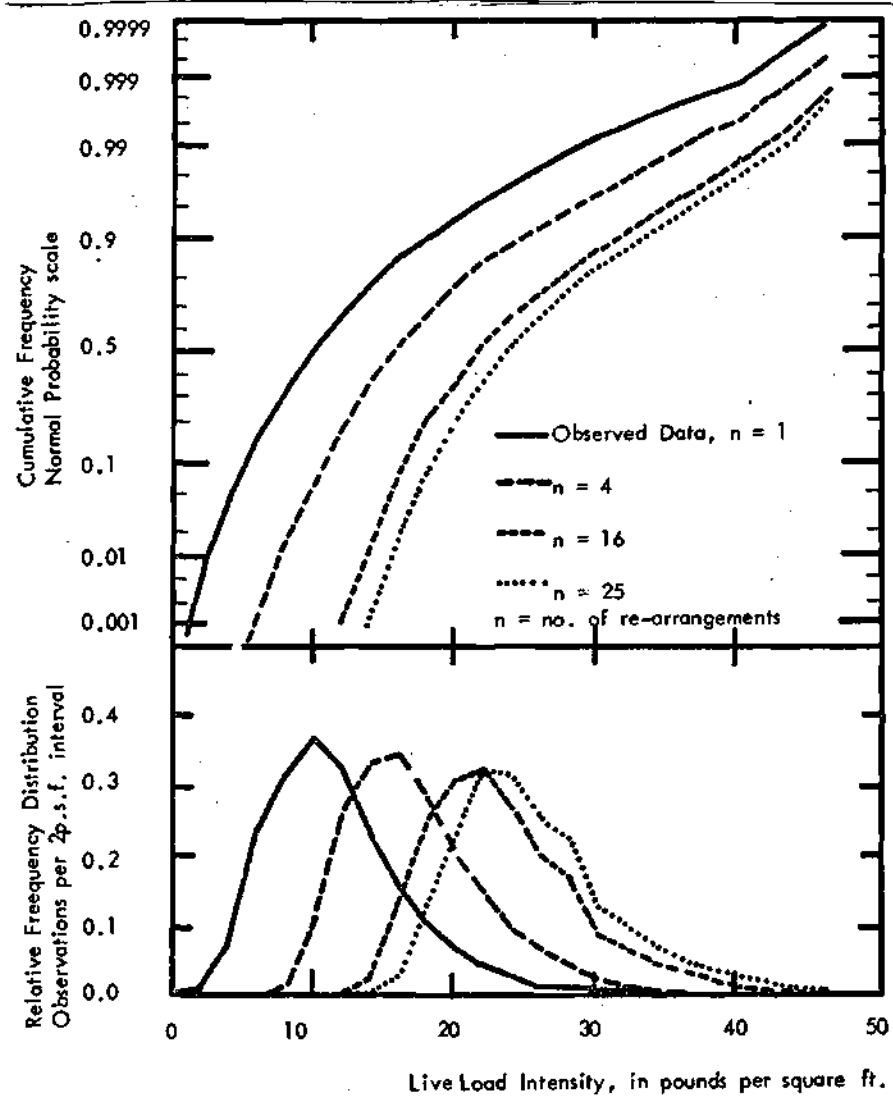


Figure 6. Maximum Loading Distribution for Different Numbers of Loading Rearrangements, Heaney.

more than ten loading rearrangements, we will consider  $n = 16$ .

Because of safety factors in the design process, a structure designed for 40 psf will fail at 80 to 90 psf; similarly, one designed for 30 psf will fail at 60 to 68 psf. Using these values and looking at the cumulative frequency graph for  $n = 16$  in Figure 7, we have,

$$F_U(80\text{psf}) = 0.99999$$

$$F_U(60\text{psf}) = 0.9996$$

We are interested in loads which exceed these values, and, consequently,

$$P[U \geq 80] = 1 - F_U(80\text{psf}) = 0.00001$$

$$P[U \geq 60] = 1 - F_U(60\text{psf}) = 0.0004$$

Setting up the following relation,

$$\frac{\text{Failure Rate at 40 psf}}{\text{Failure Rate at 30 psf}} = \frac{P(U \geq 80)}{P(U \geq 60)}$$

and substituting,

$$\frac{2.6 \times 10^{-7}}{FR_{30}} = \frac{0.00001}{0.0004}$$

yields a failure rate of  $10.4 \times 10^{-6}$  sq. ft./sq. ft./year for our office building if it is designed at a live load of 30 psf.

Using an average construction cost of \$25 per square foot, the total floor area for the building can be estimated at 10,000,000 square feet. Multiplying the failure rate for each design load by the total floor area will result in the average number of square feet failing per year.

$$\text{Failure Area for 40 psf} = 10^7 \times 2.6 \times 10^{-7} = 2.6 \text{ sq. ft./year}$$

$$\text{Failure Area for 30 psf} = 10^7 \times 10.4 \times 10^{-6} = 104 \text{ sq. ft./year}$$

In a typical failure there will be associated costs for human deaths and injuries, medical costs, lawsuits, cleanup, and decreased reputation of builder and owner in addition to the rebuilding cost. It is estimated that failure costs will run about ten times as great as the original construction cost. Using \$250 per square foot as the failure cost per square foot, the total failure cost for each design can be computed as follows:

$$\text{Failure Cost for 40 psf} = 2.6 \times \$250 = \$600/\text{year}$$

$$\text{Failure Cost for 30 psf} = 104 \times \$250 = \$26,000/\text{year}$$

The total benefits for each design can be determined by adding the positive owner benefits and the negative failure costs.

The results of the analysis are presented in Table 4. Looking at the benefit/cost ratios in Table 5, we see that designing for 30 psf is a more economical alternative. However, additional points on the

Table 5. Benefit Cost Analysis for Determining the Design Live Load

|                       | Design at<br>40 psf                                      | Design at<br>30 psf                                       |
|-----------------------|--|---|
| First Cost            | \$250,000,000  | \$225,000,000   |
| Capital Recovery Cost | \$ 26,500,000/Yr.  | \$ 23,850,000/Yr.   |
| Maintenance Cost      | \$ 100,000/Yr.   | \$ 100,000/Yr.  |
| Total Cost            | \$ 26,600,000  | \$ 23,950,000/Yr.   |
| Benefit to Owner      | \$ 27,000,000/Yr.  | \$ 26,200,000/Yr.   |
| Failure Rate          | $2.6 \times 10^{-7} \text{ Ft}^2/\text{Ft}^2/\text{Yr.}$ | $10.4 \times 10^{-6} \text{ Ft}^2/\text{Ft}^2/\text{Yr.}$ |
| Failure Benefits      | - \$600/Yr.  | - \$26,000/Yr.  |
| Total Benefits        | \$ 26,999,400  | \$ 26,174,000   |
| Benefit/Cost Ratio    | 1.01   | 1.09  |

universal design curve must be found to determine the optimal solution. It appears from the data that certain structures under present codes are being overdesigned. Failure costs for a large project are only \$600 per year, an extremely low value. Consequently, existing codes need to be revised to allow for the optimal design of all structures.

There are some projects for which live-load reduction may not be practical. Small projects in which there would not be much of a cost savings by load reduction and buildings with high tenancy turnover, in which the owner would be faced with constantly changing uses, are examples. All of these factors should be included in the economic analysis of any project.

## CHAPTER V

## CONCLUSION

One might conclude that today's structures are largely oversized, as seen in this analysis of live-load failures. In the National Bureau of Standards study (6), most of the floor area had no load on it, and even those areas loaded had a mean of only 11.4 pounds per square foot, a large variation from the 80 pounds per square foot that the National Building Code (7) states as its minimum design floor load for offices. By large outlays of resources, we can make our structures relatively safe, but we are, at the same time, placing an infinite value on human life, which may be an unreasonable figure. Instead, our goal should be to minimize the total cost of the structure, as seen in the universal design curve presented in Chapter III.

A probabilistically-based code would be a major step in this direction. Both Heaney (1) and Cornell (8) have presented examples of such codes. Currently, any structure designed has an unknown probability of failure. However, using statistics to describe the loading on and resistance of future structures, an average failure rate can be computed, which can then be related to failure cost.

To complete this type of analysis a large amount of data must be available on the magnitudes of loadings as well as the number of loadings that may occur during the lifetime of the structure. In this paper the author concentrated on failures reported in Engineering News-Record while

attempting to estimate the unreported failures. This method is certainly not one on which a design procedure should be based. Instead a data collection system for live loadings would be needed before any progress is realized. This system could operate in a number of ways either by monitoring insurance companies, reviewing lawsuits, etc.

A structure designed today has a ten-fold greater probability of failing during construction than at any other time during the lifetime of the building. Although in many instances the structure had not attained full strength, a number of live load accidents did occur after the structural integrity had been completed. Since there has not been a study on construction loadings, we cannot compare them to occupancy loads. But, because of the frequent, heavy load applications encountered during construction, it might be more desirable to design for construction loads rather than for occupancy requirements. To analyze this point, though, a number of construction load surveys must be conducted.

It is evident that much work is needed in the field of live loads before any substantial results are received. However, the goal of lower-cost, better designed structures is a necessary one.

**APPENDICES**

## APPENDIX A

## TOTAL BUILDING POPULATION

The following data for the years 1932-1971 were obtained from Construction Review for construction put in place:

| Year | Construction Value in Millions of Dollars<br>1947-1949 Prices |
|------|---|
| 1932 | 8,892 <sup>1</sup>  |
| 1933 | 6,631   |
| 1934 | 7,725   |
| 1935 | 9,081   |
| 1936 | 13,489  |
| 1937 | 13,620  |
| 1938 | 13,492  |
| 1939 | 16,080  |
| 1940 | 16,767  |
| 1941 | 21,714  |
| 1942 | 22,852  |
| 1943 | 12,812  |
| 1944 | 8,174   |
| 1945 | 8,681   |
| 1946 | 16,492  |
| 1947 | 19,062  |
| 1948 | 22,235  |
| 1949 | 23,527  |
| 1950 | 27,990  |
| 1951 | 28,327  |
| 1952 | 29,123  |
| 1953 | 30,459  |
| 1954 | 32,612  |
| 1955 | 35,702  |
| 1956 | 34,898  |

- 
- <sup>1</sup> 1932-1956: "New Construction in 1947-49 Prices," Construction Review Supplement, U. S. Department of Commerce and U. S. Department of Labor
- 1956-1971: "Construction Put in Place," Construction Review, Oct. 1966 (Vol. 12, No. 10) and Oct./Nov. 1971 (Vol. 17, No. 10-11), U. S. Department of Commerce, Bureau of Domestic Commerce

| Year | Construction Value in Millions of Dollars<br>1957-1959 Prices |
|------|---|
| 1957 | 35,003  |
| 1958 | 35,477  |
| 1959 | 40,155  |
| 1960 | 38,744  |
| 1961 | 39,652  |
| 1962 | 59,662  |
| 1963 | 62,968  |
| 1964 | 66,221  |
| 1965 | 71,930  |
| 1966 | 75,120  |
| 1967 | 76,160  |
| 1968 | 84,690  |
| 1969 | 90,866  |
| 1970 | 91,266  |
| 1971 | 104,956   |

From the National Construction Estimator an average 1971 building cost of \$25 per square foot was obtained. To convert this cost to 1957-59 and 1947-49 prices, a cost index for square foot valuation from Construction Review was used

| Year    | Cost Index For<br>Square Foot<br>Valuation | Cost Per<br>Square Foot |
|---------|--|-------------------------|
| 1971    | 146 <sup>2</sup>                           | \$25 <sup>3</sup>       |
| 1956-59 | 100  | \$17.1                  |
| 1947-49 | 67   | \$11.5                  |

Using these costs per square foot, the total square feet put in place can be computed as follows:

<sup>2</sup> "Trends in Valuation Per Square Foot of Building Floor Area, 1956-68," Construction Review, November 1969, Vol. 15, No. 11, U. S. Department of Commerce, Bureau of Domestic Commerce

<sup>3</sup> Moselle, G., National Construction Estimator, Craftsman Book Company, Los Angeles, 1970.

| Year | Square Feet Put In Place |
|------|--------------------------|
| 1932 | 773,217,000              |
| 1933 | 576,608,000              |
| 1934 | 671,739,000              |
| 1935 | 789,652,000              |
| 1936 | 1,172,956,000            |
| 1937 | 1,184,348,000            |
| 1938 | 1,173,217,000            |
| 1939 | 1,398,261,000            |
| 1940 | 1,458,000,000            |
| 1941 | 1,888,174,000            |
| 1942 | 1,987,130,000            |
| 1943 | 1,114,087,000            |
| 1944 | 710,783,000              |
| 1945 | 754,869,000              |
| 1946 | 1,434,087,000            |
| 1947 | 1,657,565,000            |
| 1948 | 1,933,478,000            |
| 1949 | 2,045,826,000            |
| 1950 | 2,433,913,000            |
| 1951 | 2,463,217,000            |
| 1952 | 2,532,435,000            |
| 1953 | 2,648,609,000            |
| 1954 | 2,835,826,000            |
| 1955 | 3,104,522,000            |
| 1956 | 3,034,609,000            |
| 1957 | 2,046,959,000            |
| 1958 | 2,074,678,000            |
| 1959 | 2,348,246,000            |
| 1960 | 2,265,731,000            |
| 1961 | 2,318,830,000            |
| 1962 | 3,489,298,000            |
| 1963 | 3,682,339,000            |
| 1964 | 3,872,573,000            |
| 1965 | 4,206,433,000            |
| 1966 | 4,392,982,000            |
| 1967 | 4,453,801,000            |
| 1968 | 4,952,631,000            |
| 1969 | 5,313,801,000            |
| 1970 | 5,337,193,000            |
| 1971 | 6,137,778,000            |

Assuming a thirty-year building life, a total population for each year from 1962 to 1971 can be obtained by adding the square feet put in place during the previous thirty years.

| Year | Total Population in Square Feet |
|------|---------------------------------|
| 1962 | 56,320,000,000                  |
| 1963 | 59,229,000,000                  |
| 1964 | 62,525,000,000                  |
| 1965 | 66,061,000,000                  |
| 1966 | 69,281,000,000                  |
| 1967 | 72,550,000,000                  |
| 1968 | 76,330,000,000                  |
| 1969 | 80,245,000,000                  |
| 1970 | 84,124,000,000                  |
| 1971 | 88,374,000,000                  |

Averaging the above values together yields a mean of  $72 \times 10^9$  square feet for the ten year period.

## APPENDIX B

STRUCTURAL FAILURES REPORTED IN ENGINEERING NEWS RECORD 1962-1971

|     | Date           | Location                | Type of Failure | Type of Building           |
|-----|----------------|-------------------------|-----------------|----------------------------|
| 1.  | July 5, 1962   | Fort Worth, Texas       | (1)*            | 7-Story Motel              |
| 2.  | Aug. 23, 1962  | Richmond, Ky.           | (3)             | Coliseum                   |
| 3.  | Sept. 20, 1962 | Brussels, Belgium       | (1)             | Government Building        |
| 4.  | Nov. 8, 1962   | Atlanta, Georgia        | (1)             | 1-Story School             |
| 5.  | Jan. 3, 1963   | New York, N. Y.         | (2)             | Underground Garage         |
| 6.  | Mar. 14, 1963  | Dearborn, Mich.         | (4)             | 60-Unit Motel              |
| 7.  | Sept. 19, 1963 | Bermuda Hundred, Va.    | (1)             | Tobacco Plant              |
| 8.  | Sept. 26, 1963 | Ocala, Florida          | (4)             | Courthouse Roof            |
| 9.  | Nov. 7, 1963   | Washington, D. C.       | (1)             | 10-Story Apt. Building     |
| 10. | Dec. 19, 1963  | St. Louis, Mo.          | (1)             | School Gym                 |
| 11. | Jan. 23, 1964  | Paris, France           | (1)             | 10-Story Art.              |
| 12. | Jan. 30, 1964  | Santa Clara, California | (5)             | Warehouse                  |
| 13. | Apr. 9, 1964   | Madrid, Spain           | (1)             | Underground Garage         |
| 14. | June 25, 1964  | Merrit Island, Fla.     | (4)             | Vertical Assembly Building |
| 15. | Sept. 17, 1964 | Washington, D. C.       | (3)             | National Press Building    |
| 16. | Oct. 29, 1964  | Alexandria, La.         | (1)             | Coliseum                   |
| 17. | Oct. 29, 1964  | Cairo, Egypt            | (5)             | 5-Story Apartment          |
| 18. | Oct. 29, 1964  | Ottawa, Canada          | (1)             | 2-Story Brick Building     |

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\* See page 44.

|     |               |                       |     |                         |
|-----|---------------|-----------------------|-----|-------------------------|
| 19. | Jan. 7, 1965  | Rijo, Mexico          | (2) | Church                  |
| 20. | Mar. 25, 1965 | Cleveland, Ohio       | (1) | Warehouse               |
| 21. | May 13, 1965  | Atlanta, Georgia      | (1) | Shopping Center Store   |
| 22. | May 13, 1965  | Jacksonville, Florida | (4) | Church Addition         |
| 23. | May 20, 1965  | Atlanta, Georgia      | (1) | 1-Story Retail Store    |
| 24. | May 20, 1965  | Italian Rivera        | (2) | 8-Story Apartment       |
| 25. | May 27, 1965  | Brooklyn, N. Y.       | (3) | Supermarket             |
| 26. | July 22, 1965 | West Des Moines, Ia.  | (5) | Church                  |
| 27. | July 29, 1965 | Concord, N. H.        | (1) | 5-Story Office Building |
| 28. | Aug. 19, 1965 | Jacksonville, Fla.    | (5) | 11-Story Apartment      |
| 29. | Oct. 14, 1965 | Platteville, Wis.     | (1) | University Building     |
| 30. | Jan. 6, 1966  | Vinqaaker, Sweden     | (3) | Sports Hall             |
| 31. | Feb. 3, 1966  | New York, N. Y.       | (4) | Factory                 |
| 32. | Feb. 24, 1966 | Stockholm, Sweden     | (5) | Curling Rink            |
| 33. | Apr. 7, 1966  | Ottawa, Canada        | (1) | 12-Story Apt. Bldg.     |
| 34. | Apr. 28, 1966 | St. Louis, Mo.        | (3) | 3-Story Apt. Bldg.      |
| 35. | May 19, 1966  | Athens, Greece        | (1) | Papermill Addition      |
| 36. | May 19, 1966  | Kingston, Jamaica...  | (1) | Storage Building        |
| 37. | May 19, 1966  | Catania, Sicily       | (5) | Theater                 |
| 38. | May 19, 1966  | Dallas, Texas         | (4) | Trade Mart              |
| 39. | June 2, 1966  | Michigan              | (5) | Parking Garage          |
| 40. | June 9, 1966  | Pittsburgh, Pa.       | (5) | University Building     |
| 41. | Aug. 18, 1966 | Hamilton, Ont.        | (5) | Steel Framework         |
| 42. | Sept. 1, 1966 | Atlanta, Georgia      | (2) | Chapel                  |

|     |                |                         |     |                             |
|-----|----------------|-------------------------|-----|-----------------------------|
| 43. | Sept. 29, 1966 | Dallas, Texas           | (3) | Exhibit Building            |
| 44. | Nov. 10, 1966  | Aberdeen, Scotland      | (1) | 7-Story University Building |
| 45. | Dec. 22, 1966  | San Francisco, Calif.   | (1) | Dockside Shed               |
| 46. | Feb. 16, 1967  | Lansing, Mich.          | (5) | Bowling Alley               |
| 47. | Feb. 16, 1967  | Baltimore, Md.          | (5) | Church                      |
| 48. | Feb. 16, 1967  | Minneapolis, Minn.      | (5) | Exhibit Building            |
| 49. | Mar. 16, 1967  | New York, N. Y.         | (1) | Lincoln Center              |
| 50. | Apr. 13, 1967  | Macomb, Michigan        | (5) | School Building             |
| 51. | May 18, 1967   | Fort Worth, Texas       | (1) | Library                     |
| 52. | Aug. 3, 1967   | Blackstone, Mass.       | (5) | Department Store            |
| 53. | Aug. 24, 1967  | South Weymouth, Mass.   | (3) | Hangar                      |
| 54. | Dec. 14, 1967  | Richmond, Va.           | (5) | School Gym                  |
| 55. | Jan. 11, 1968  | Chapel Hill, N. C.      | (1) | University Building         |
| 56. | June 13, 1968  | Arlington, Va.          | (1) | 12-Story Building           |
| 57. | Sept. 12, 1968 | New York, N. Y.         | (4) | 42-Story Building           |
| 58. | Oct. 31, 1968  | New York, N. Y.         | (1) | 50-Story Building           |
| 59. | Nov. 7, 1968   | Kuala Lumpur, Malaysia  | (1) | 4-Story Building            |
| 60. | Nov. 21, 1968  | San Antonio, Texas      | (3) | 1-Story Building            |
| 61. | Dec. 5, 1968   | Buenos Aires, Argentina | (4) | Apartment Building          |
| 62. | Dec. 12, 1968  | Greenwich, Conn.        | (5) | 4-Story Office Building     |
| 63. | Mar. 6, 1969   | Dayton, Ohio            | (1) | Fieldhouse                  |
| 64. | Mar. 13, 1969  | Pittsburgh, Pa.         | (1) | Hospital                    |
| 65. | June 19, 1969  | Madrid, Spain           | (4) | Restaurant                  |
| 66. | Aug. 7, 1969   | Buenos Aires, Argentina | (1) | 22-Story Apt. Bldg.         |
| 67. | Sept. 18, 1969 | Rockville, Md.          | (1) | 7-Story Office Bldg.        |

|     |                |                          |     |                      |
|-----|----------------|--------------------------|-----|----------------------|
| 68. | Dec. 11, 1969  | Akron, Ohio              | (3) | Department Store     |
| 69. | Jan. 1, 1970   | Monroe, Tennessee        | (2) | 2 School Gyms        |
| 70. | Jan. 8, 1970   | Trivandrum, Indiana      | (3) | Auditorium           |
| 71. | Jan. 15, 1970  | Old Orchard Beach, Maine | (5) | Gym                  |
| 72. | Feb. 19, 1970  | San Francisco, Calif.    | (1) | Airport Building     |
| 73. | Feb. 26, 1970  | Buenos Aires, Argentina  | (1) | 15-Story Apt. Bldg.  |
| 74. | Mar. 5, 1970   | Pittsburgh, Pa.          | (4) | 20-Story Apt. Bldg.  |
| 75. | Apr. 23, 1970  | Omaha, Neb.              | (3) | Parking Garage       |
| 76. | June 25, 1970  | Winston-Salem, N. C.     | (5) | Auditorium           |
| 77. | Sept. 3, 1970  | Milan, Italy             | (3) | Parking Garage       |
| 78. | Sept. 17, 1970 | New York, N. Y.          | (1) | Motel Addition       |
| 79. | Sept. 24, 1970 | Richmond, Virginia       | (2) | School Gym           |
| 80. | Nov. 5, 1970   | Louisiana                | (1) | Civic Auditorium     |
| 81. | Jan. 28, 1971  | Boston, Mass.            | (4) | 16-Story Luxury Apt. |
| 82. | Feb. 18, 1971  | Brazil                   | (3) | Exposition Center    |
| 83. | Mar. 25, 1971  | Arlington, Virginia      | (1) | Parking Garage       |
| 84. | Apr. 19, 1971  | Malaga, Spain            | (4) | Hotel                |

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\* Type/Cause of Accident:

- (1) incorrect construction techniques
- (2) poor design
- (3) cause unknown
- (4) excess live load
- (5) excess rain, snow, or wind loads

## APPENDIX C

## INSURANCE COMPANY DATA

The following data was not used in this study but were included because of their possible interest.

## Georgia Structural Engineers

| Billings | Construction<br>Value in Million<br>Dollars | Limit of<br>Liability | Deductible | Total<br>Premiums |
|----------|---|-----------------------|------------|-------------------|
| 350,000  | 75  | 250,000               | 5000       | 6274              |
| 78,000   | 2.75  | 100,000               | 2000       | 900               |
| 200,000  | 2.0   | 100,000               | 2000       | 2276              |
| 58,842   | 1.5   | 250,000               | 3000       | 1191              |
| 30,000   | 1.0   | 250,000               | 4000       | 753               |
| 269,834  | 70  | 200,000               | 10000      | 4414              |

Incurred loss ratio\* 61.92%

Total premiums for 1970 \$33,645

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\* Incurred loss - total money spent on claims plus any reserve kept for future suits.

Incurred loss ratio - incurred loss/total premiums paid

NATIONWIDE ARCHITECTS AND ENGINEERS PROFESSIONAL LIABILITY PROGRAM

LOSS EXPERIENCE BY CLASS OF WORK AS OF 9/30/71

| 1956-1963            | Number of Current Insureds | Earned Premium    | Incurred Loss     | Incurred Loss Ratio |
|----------------------|----------------------------|-------------------|-------------------|---------------------|
| Architects           | 106                        | 7,169,220         | 8,312,199         | 115.94%             |
| Electrical Engineers | 5                          | 220,247           | 70,671            | 32.08%              |
| Mechanical Engineers | 16                         | 1,249,479         | 1,529,357         | 122.39%             |
| Structural Engineers | 14                         | 1,262,194         | 1,913,296         | 151.58%             |
| Civil Engineers      | 20                         | 3,958,308         | 4,019,768         | 101.55%             |
| Combined Firms       | 8                          | 3,311,670         | 3,959,482         | 119.56%             |
| Land Surveyor        | 0                          | 0                 | 7,991             | .00%                |
| Retired Firms        | 0                          | 0                 | 0                 | .00%                |
| Landscape Architects | 1                          | 1,982             | 0                 | .00%                |
| Others               | 0                          | 2,025             | 51,774            | 2,556.74%           |
| <b>TOTAL</b>         | <b>170</b>                 | <b>17,175,125</b> | <b>19,864,538</b> | <b>115.65%</b>      |
|                      |                            |                   |                   |                     |
| 1963-8/69            |                            |                   |                   |                     |
| Architects           | 242                        | 19,277,327        | 17,823,251        | 92.45%              |
| Electrical Engineers | 2                          | 713,835           | 332,051           | 46.51%              |
| Mechanical Engineers | 8                          | 3,723,135         | 1,518,002         | 40.77%              |
| Structural Engineers | 11                         | 3,253,095         | 5,346,425         | 164.34%             |
| Civil Engineers      | 49                         | 8,974,250         | 7,729,103         | 86.12%              |
| Combined Firms       | 99                         | 8,268,036         | 9,855,087         | 119.19%             |
| Land Surveyor        | 0                          | 5,018             | 0                 | .00%                |
| Retired Firms        | 59                         | 79,033            | 120,184           | 152.06%             |
| Landscape Architects | 0                          | 16,682            | 0                 | .00%                |
| Others               | 7                          | 451,288           | 107,418           | 23.80%              |
| <b>TOTAL</b>         | <b>477</b>                 | <b>44,761,699</b> | <b>42,831,521</b> | <b>95.68%</b>       |

|                      | Number of Current<br>Insureds | Earned Premium | Incurred Loss | Incurred Loss<br>Ratio |
|----------------------|-------------------------------|----------------|---------------|------------------------|
| 1956-8/69            |                               |                |               |                        |
| Architects           | 348                           | 26,446,547     | 26,135,450    | 98.82%                 |
| Electrical Engineers | 7                             | 934,082        | 402,722       | 43.11%                 |
| Mechanical Engineers | 24                            | 4,972,614      | 3,047,359     | 61.28%                 |
| Structural Engineers | 25                            | 4,515,289      | 7,259,721     | 160.78%                |
| Civil Engineers      | 69                            | 12,932,558     | 11,748,871    | 90.84%                 |
| Combined Firms       | 107                           | 11,579,706     | 13,814,569    | 119.29%                |
| Land Surveyor        | 0                             | 5,018          | 7,991         | 159.24%                |
| Retired Firms        | 59                            | 79,033         | 120,184       | 152.06%                |
| Landscape Architects | 1                             | 18,664         | 0             | .00%                   |
| Others               | 7                             | 453,313        | 159,192       | 35.11%                 |
| TOTAL                | 647                           | 61,936,824     | 62,696,059    | 101.22%                |
| 8/69-12/71           |                               |                |               |                        |
| Architects           | 4,837                         | 13,954,283     | 5,130,172     | 36.76%                 |
| Electrical Engineers | 198                           | 490,651        | 90,852        | 18.51%                 |
| Mechanical Engineers | 719                           | 2,486,799      | 519,159       | 20.87%                 |
| Structural Engineers | 625                           | 2,712,230      | 1,195,199     | 44.06%                 |
| Civil Engineers      | 1,115                         | 6,991,783      | 2,438,965     | 34.88%                 |
| Combined Firms       | 696                           | 6,919,237      | 4,110,368     | 59.40%                 |
| Land Surveyor        | 0                             | 13,578         | 0             | .00%                   |
| Retired Firms        | 23                            | 4,448          | 0             | .00%                   |
| Landscape Architects | 0                             | 0              | 0             | .00%                   |
| Others               | 39                            | 291,227        | 58,849        | 20.20%                 |
| TOTAL                | 8,252                         | 33,864,236     | 13,543,564    | 39.99%                 |

|                      | Number of Current<br>Insureds | Earned Premium    | Incurred Loss     | Incurred Loss<br>Ratio |
|----------------------|-------------------------------|-------------------|-------------------|------------------------|
| 1956-12/71           |                               |                   |                   |                        |
| Architects           | 5,185                         | 40,400,830        | 31,265,622        | 77.38%                 |
| Electrical Engineers | 205                           | 1,424,733         | 493,574           | 34.64%                 |
| Mechanical Engineers | 743                           | 7,459,413         | 3,566,518         | 47.81%                 |
| Structural Engineers | 650                           | 7,227,519         | 8,454,920         | 116.98%                |
| Civil Engineers      | 1,184                         | 19,924,341        | 14,187,836        | 71.20%                 |
| Combined Firms       | 803                           | 18,498,943        | 17,924,937        | 96.89%                 |
| Land Surveyor        | 0                             | 18,596            | 7,991             | 42.97%                 |
| Retired Firms        | 82                            | 83,481            | 120,184           | 143.96%                |
| Landscape Architects | 1                             | 18,664            | 0                 | .00%                   |
| Others               | 46                            | 744,540           | 218,041           | 29.28%                 |
| <b>TOTAL</b>         | <b>8,899</b>                  | <b>95,801,060</b> | <b>76,239,623</b> | <b>79.58%</b>          |

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