EARTHQUAKE LOAD PROVISIONS OF THE NATIONAL BUILDING CODE OF CANADA

by

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Many of the building codes of those countries that are subjected to earthquakes provide provisions for the determination of earthquake loads. The earthquake resistant design of a building is meant to account for the response of the structure to a complex and chaotic ground motion, the nature of which is not known in advance. As a result the earthquake load provisions of building codes can only specify design and structural requirements intended to account for the effect of an arbitrary earthquake.

The object of this paper is to discuss the earthquake load provisions of the National Building Code of Canada and to compare them with those of some other building codes. The provisions incorporate some of the theoretical and practical knowledge of earthquake engineering that has been accumulated over the last 30 or 40 years.

Earthquake Design Factors

A survey of nineteen earthquake resistant regulations(1) shows that some or all consider thirteen major design factors. These are shown in Table 1, together with the number of building codes that take account of each factor. Each of these factors will be discussed briefly and the manner in which some of the building codes take account of the factors will be compared.

Building Code Methods of Calculating and Distributing Base Shear

Nineteen of the building codes provide for the calculation and distribution of base shear caused by earthquakes. In all cases the base shear force, V_B, is calculated from an expression of the form,

$$V_B = K \times W \quad \dots\dots\dots\dots\dots\dots (1)$$

where K is a function of some of the factors given in Table 1, and W is the total weight of the building. Two different prevalent design concepts lead to an expression of the form shown in equation (1) for the

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base shear, but the method of distributing the force through the height of the building is different.

The simplest design procedure is to assume that the structure moves as a rigid body. The base shear force at any instant is then a function of the total mass of the building and the foundation acceleration, $\ddot{x}_f$, at that instant (Figure 1A). This approach reduces earthquake design to the problem of determining a suitable maximum ground acceleration that defines a region's seismic activity. The lateral force acting at any floor level is obtained by multiplying the weight of that floor by the ratio of the ground acceleration to the acceleration due to gravity (Figure 1B). The rigid body approach is used by 10 of the 19 building codes, including the Japanese building code, which provides for a value of K between 0.1 and 0.2, depending on the region, the type of structure and the foundation soil.

Beginning with Biot's(2) work in the early 1940's an increasing amount of work has since been devoted to the concept of a flexible structure. In this case, the structure will deflect with respect to the position of the foundation (Figure 2A). If the structure is assumed to be a lumped mass system, the problem is reduced to the solution of a system of second-order simultaneous equations. These equations are formulated in terms of the distribution of mass and stiffness in a structure, together with its damping characteristics and the dynamic characteristics of the ground motion .

The detailed aspect of this part of the problem has been dealt with in a preceding paper(3) and so we can consider the situation shown in Figure 2B. A three-storey building is shown at an instant during a vibration in the fundamental mode specified by an angular velocity ω. The lateral inertia force acting at any floor is given by a term of the form $\frac{W\omega^2}{g}x$, but Figure 2B shows that this can be written as $\frac{W\omega^2\alpha h}{g}$ if the mode of vibration is considered to be a linear function of height. In this case the base shear, V_B, is given by

$$V_B = \left(\frac{\alpha\omega^2}{g}\right)\sum_{i=1}^{N} W_i h_i \quad , \qquad (2)$$

where N is the number of storeys. The lateral force, F_i, acting at the i^{th} floor can now be written in the form,

$$F_i = W_i h_i\left(\frac{\alpha\omega^2}{g}\right) = \frac{W_i h_i}{\sum_{i=1}^{N} W_i h_i} V_B \qquad (3)$$

The value of the base shear to be used in equation (3) depends on the solution of the second order differential equations. If the structure is considered to be a single-degree-of-freedom system, then it is possible to calculate the maximum base shear acting on the structure by evaluating the maximum velocity of vibration, S_V, that occurs during the ground motion. This introduces the concept of velocity spectrum curves and Figure 3 shows smoothed curves that have been obtained by Housner(4) using actual strong-motion records. The values of S_v are plotted as a function of the period, T, of the structure and the percentage of critical damping. The base shear for any given structure is given by

$$V_B = \frac{2\pi S_v}{gT} \times W, \qquad (4)$$

which is of the form K x W. It can be shown that the fundamental period of a building will increase with the number of storeys, and the following expression is known to be quite accurate for tall buildings (>25 storeys),

$$T = 0.1N. \qquad (5)$$

It is then possible to plot values of the earthquake load parameter K of equation (4) as a function of N. This has been done in Figure 4 for two cases of zero and 10% of critical damping.

NBC Earthquake Load Parameter K

The earthquake load parameter, K, of the 1965 National Building Code is expressed as follows,

$$K = R \times C \times I \times F \times S, \qquad (6)$$

where R.C.I and F are four of the factors included in Table 1; R is a regional seismic factor, C depends on the type of structure, I depends on the use of the building and F is a function of the foundation soil conditions. S is a function of the number of storeys in the building ($S = \frac{0.25}{n + 9}$), and in Figure 5 the maximum (Case A) and minimum (Case B) values of K for zone 3 (R = 4) are plotted as a function of the number of storeys, N. A comparison of Figures 4 and 5 shows that they have the same general form although the values of K in Figure 5 are smaller.

The S factor in the 1965 National Building Code is, therefore, based on the observation that the base shear caused by an earthquake appear to be inversely proportional to the period of natural vibration of the structure. In the 1961 Uniform Building Code(5) the period is explicitly included in the parameter K, but since this is a field of continuing research, this was not attempted in the 1965 National Building Code.

Nine of the building codes have earthquake load parameters that are based on the concept of a flexible structure, althouth in each instance the values are smaller by a factor of 4 or 5 than those calculated by Housner for large earthquakes. This is probably due to the fact that past experience has shown that buildings designed for these smaller values have successfully withstood earthquakes (for example the value of K for the 43-storey Torre Latino Americana in Mexico City was measured at 0.033 during an earthquake in 1957(6)).

The distribution of base shear through the height of a building is accomplished in the 1965 National Building Code by means of equation (3). This means it is assumed the building vibrates in the fundamental mode and that this mode is a linear function of height. It appears that both these assumptions are realistic although it is possible that the higher modes of tall buildings will have a significant effect on the earthquake loads. This is on account of the fact that the frequencies of these higher modes will be nearer to the predominant frequencies of strong-motion earthquakes (1-5cps). The Soviet, French and Roumanian building codes allow for the consideration of the higher modes of vibration, but the application of these codes requires a determination of the natural modes and frequencies of vibration of the building.

If the structural designer wishes to allow for the higher modes of vibration, he is permitted to do so by the National Building Code since clause 4.1.3.15(1) states: "The design loading due to earthquake motion may be determined by a simple statical analysis as provided for in Sentence (4) (equation 1), or may be determined by a dynamic analysis, where such an analysis is carried out by a person competent in this field of work." The National Building Code, however, does not provide any guide as to the method of dynamic analysis to be used.

Figure 6, shows a comparison of the earthquake load parameter, K, according to the 1960 and 1965 National Building Codes for zone 3. The Case B curve of the 1965 code represents the minimum K value, and the Case C curve represents the most probable design curve for buildings on a good foundation material. This shows that the base shear as calculated by the two editions of the code will not be too different. The forces acting at different levels of the building will be different, however, since the method of distributing the base shear has been changed to that shown in equation (3).

The difference is shown in Table 2 where the value of the force acting at the top of a building of N storeys in zone 3 is given. The results in this table are based upon the assumption that each storey height and the weight of each floor, W, are equal. The 1961 Uniform Building Code requires that 10% of the base shear be placed at the top floor if the height to the depth ratio of a lateral force resisting system is equal to or greater than five to one. This idea probably arose because there is a tendency for the upper floors of tall buildings to be quite flexible, and heavy service equipment is also generally placed near the top of the buildings. This concept has not been included in the 1965 National Building Code, but as more research and information become available, such a provision may be justified.

Seismic Regionalization and Foundation Soil Conditions

The earthquake load parameter, K, of the 1965 National Building Code contains a seismic regionalization factor, R, and a foundation soil factor, F. These will be considered together since their influences overlap.

In a recent paper, Hodgson(7) has reviewed the earthquake risks associated with Canada. He points out that the Soviet Union have pioneered the production of seismic regionalization maps; these maps are based upon seismic information gathered by such scientific disciplines as geophysics, geology, seismology and geodetic survey. Similar work is being carried out by the Canadian Department of Mines and Technical Surveys, and eventually the National Building Code may include such information. In the meantime, the earthquake probability map of the Climatological Atlas(8) provides the basis for the seismic regionalization factor, R, in equation (6). As pointed out by Hodgson, the map is based on what was known about past earthquakes, and what geological theory suggested about the probable occurrence of earthquakes. The earthquake probability map divides Canada into four zones numbered 0, 1, 2 and 3, and the corresponding values for R are 0, 1, 2, and 4. The same zones and range of values for 4 are employed by the 1961 Uniform Building Code.

One of the striking lessons demonstrated time and again by the occurrence of earthquakes is the effect that the foundation soil has on the damage experienced by buildings. In the 1906 San Francisco earthquake, the greatest proportion of earthquake damage occurred to buildings that were placed on fill material. During the 1957 Mexican earthquake(9) 99% of the damaged buildings were founded on the highly compressible volcanic clay strata of the old lake bed, and only 1% of the damaged buildings were founded on the incompressible material of the Sierra.

The indications, therefore, are that it is better to found a building on an incompressible material than on a compressible material if the structure is in an earthquake zone. The 1965 National Building Code includes a foundation soil factor, F, that is equal to 1.5 for highly compressible soil and has the value 1.0 for other soil conditions. The 50% increase in loading for buildings on compressible material may not be conservative since 6 of the 12 codes that take account of foundation soil conditions require a 100% increase in loading when going from an incompressible to a compressible soil. As more research and information become available, it will be possible to bring the F factor in the National Building Code up-to-date, but in its present simple form, it probably provides a first order approximation of the effect of soil conditions on earthquake loads.

The Chilean, Japanese and Mexican building codes include foundation factors that depend on the type of structure and the soil conditions. For example, in the Japanese code a wood structure placed on rock is designed for avalue of F = 0.6, but if the structure is placed on a soft foundation, F = 1.5. In effect, the Japanese code indicates that it is best to put a flexible structure on a rigid soil and a rigid structure on a compressible soil. A considerable amount of research is being done in the field of the interaction of structures and soil and eventually this material should be incorporated in building codes probably in a manner similar to the Japanese code.

The type of foundation (spread footing, piles, etc.) is also known to influence the amount of damage that a building suffers during an earthquake. Experience from past earthquakes has shown that the foundations of a building should act in an integral manner if damage is to be minimized. Thus, many of the building codes, including the National Building Code, recommend that foundation units be tied together. Only the French building code provides soil factors that depend upon the type of foundation construction.

Use of Building

The use of a structure should be in important consideration in the earthquake load provisions of a building code. This follows since one of the main objects of such provisions is to minimize the loss of life in the event of an earthquake, and also to ensure that essential facilities are available to contend with any emergency measures that stem from earthquakes.

This sort of consideration led to the inclusion in the 1965 edition of the National Building Code of a factor designated I, the value of which depends on the use of the building. I has the value 1.3 for buildings in which large numbers of people assemble, or which are important for public well-being, and 1.0 for other buildings. In the building codes that consider the use of the building as a design factor, the increase in design load due to the I factor varies from 30% to 100%.

Type of Structure

The ability to withstand large deformations without collapsing is an important asset in a structure that has to withstand earthquakes. The energy absorbed in plastic deformations reduces the dynamic response of the building and in so doing limits the lateral forces developed in the structure. On the other hand, if the structure does not possess this capability, it must be designed for a comparatively larger load. Steinbrugge and Bush(10) have indicated that framed buildings incorporating shear walls, or monolithic reinforced concrete structures, that are properly designed and constructed, have shown themselves to be a safe type of construction in earthquake zones. Braced structures or buildings that do not possess a structural second line of defence (structural redundancies) are not so satisfactory.

The 1965 National Building Code includes a factor C, that is dependent on the type of construction. For buildings that can withstand large deformations (frames with moment-resistant connections) or types of construction that have proven themselves in past earthquakes (shear wall construction) the value of C is 0.75; for other types of structures the value is 1.25. The 1961 UBC considers five types of construction with values of C that vary from 0.67 for moment-resistant frames, to 1.50 for a type of construction that is not described explicitly in the building code. At the time when revisions were being considered for the 1965 edition of the National Building Code, the division of C into more than two values was contemplated, but the necessary information was not available at that time to justify such a fine division. This may be forthcoming as more material is accumulated about the behavior of buildings during earthquakes.

Vertical Seismic Forces and Forces for Attached Structures

Most building codes consider only the lateral forces that are created by earthquakes, but in actual fact large vertical accelerations can also occur, particularly in epicentral regions. The reason for neglecting this aspect of earthquake loading is generally attributed to the reserve vertical strength possessed by most structures. Five of the building codes that have been studied consider the effect of vertical loads. Four of these codes call for increases to the dead load from 7% to 40%; the Roumanian code considers the effects of vertical loads on struts only, in which case the load is increased by 100%. The National Building Code does not consider vertical loading caused by earthquakes, but this problem is now under review.

Quite frequently, it has been found that structures which are attached to the main body of a building constitutes a danger to life and limb during an earthquake. For example, there are many instances where parapet or curtain wall sections have been torn from their supports and caused loss of life. In view of this situation, it has become common practice in building codes to specify high design earthquake loads for such parts of buildings. The National Building Code specifies a K value that can be as large as 0.8 in zone 3; the largest K value specified by any code for such structures is that of the Roumanian code where the value is 1.4. The approach of all building codes to that problem is similar in that they specify a higher design load than that for the main structures.

Torsional Forces and Overturning Moment

Damage from torsional loads caused by earth quakes has been observed in many buildings. Such damage can be attributed to an underestimate of the eccentricity between the centre of mass and the centre of rigidity. Six of the building codes incorporate provisions that require the calculation of torsional forces, thus indicating an awareness of the importance of such loads in earthquake resistant design. There is a scarcity of data on the actual torsional loads exerted during earthquakes and the building code approaches tend to be rather arbitrary.

The National Building Code specifies that the eccentricity used for the calculation of torsional loads shall equal 1.5 times the computed eccentricity, plus or minus an accidental eccentricity equal to 5% of the plan dimensions. These recommendations are based upon those of the Mexican Code which in turn have been based on theoretical work by Bustamante and Rosenblueth(11) Figure 7(a) shows the distribution of torsional loads, calculated according to the National Building Code, that act on a symmetrical ten-storey building when the weight of each floor is 1,000 Kips.

The lateral forces generated by an earthquake produce an overturning moment which must be resisted at the base of the structure. Perhaps the most striking examples of the effect of these overturning moments has been provided by the 1964 Niigata earthquake(12) where buildings were tilted or completely turned over on their sides, although these extreme cases are mainly attributed to a failure of the foundation soil.

The overturning moment, M, is calculated from the National Building Code by using the formula

$$M = F_x h_x, \qquad (7)$$

where F_x is the lateral force at the level of x and h_x is the height in feet above the base. This overturning moment is resisted by the stabilizing moment of the building's own weight, and these two moments for a ten-storey building are shown in Figure 7(b). The overturning moments as calculated by equation (7) will always be quite large. Other building codes that explicitly allow for overturning moments allow up to a 50% reduction of the overturning moment as calculated by equation (7), and some recent work by Bustamante (13) may provide the basis for some sort of revision of the National Building Code.

Drift Limitation and Separation of Buildings

The deflections of buildings in the event of an earthquake give rise to two design considerations. One of these is the possible collapse of rigid interior partitions or glazing as a result of excessive deformations of the frame. Such collapse could be the cause of loss of life and the French and Mexican Building Codes account for this by imposing a drift limitation clause. In effect, both these codes require that the deflections at any height, h, due to the earthquake loads must be less than 0.004 h to 0.001 h, depending on the building code.

The second factor that is influenced by structural deformations is the distance by which adjacent buildings should be separated. This is an important question because there are many examples where damage has been caused by two buildings coming together during an earthquake. Of the building codes that explicitly account for building separation, the recommended value is of the order 0.005H, where H is the height of the building.

Drift limitation and building separation are not covered by the National Building Code, but they are factors that Canadian designers should consider if they are designing in an earthquake zone.

Allowable Stresses.

Most building codes allow an increase in the design stress for earthquake loads. This increase is probably based on the knowledge that the behaviour of some materials to dynamic loading is different to that of static loading; for example, the yield stress of steel increases with rate of strain. Because there is limited information on this factor, the question of allowing an increase in design stress for earthquake loads needs careful consideration.

Japanese building code specifies earthquake loads that are nearly twice as large as that of other building codes, but they permit high design stresses. The other building codes specify lower earthquake loads, but except for the National Building Code, they permit an increase in working stress of the order of 33%. The National Building Code does not permit an increase in working stress for earthquake loads alone. It is suggested that a future revision of the National Building Code should specify that earthquake loads be calculated as follows. First, the loads should be calculated with dead load plus 25% of the design live load with no increase in working stress, then with dead load plus full design live load and a 33% increase in working stress. This would then place the increase in design stress on a logical basis since it is allowing for the probability of maximum earthquake and live load occurring simultaneously. The provision for no increase in design stress for the earthquake loads alone is also consistent since the loads are those due to a small earthquake that can be thought of having a good chance of occurrence say in a thirty-year return period.

Comparison of Four Building Codes

The earthquake load provisions of three building codes are compared with the 1965 National Building Code by considering the earthquake design of four buildings, the details of which are shown in Table 3. The building codes that have been used for comparison are the Mexican, the Soviet and the Uniform Building Code. These were chosen since they have all been revised in the last few years to include the latest information that was available to the code writers of those countries.

Table 4 shows the base shears as computed by the four buildings. Values of base shear are given in the direction of the two principal axes of the building. It is assumed that the buildings are in zone 3 and the values for C, F and I in equation (6) are 0.75, 1.0 and 1.3 respectively. It can be seen that the Soviet Code gives higher values than the National Building Code and Uniform Building Code for all four buildings, and the Mexican code gives higher values than these for the two taller buildings. The values of the National Building Code and the Uniform Building Code are quite close to each other, however, and since the Uniform Building Code has proven itself in Californian and Alaskan earthquakes, this is an indication that the application of the National Building Code provisions will provide structures that can withstand earthquakes. A comparison of the way in which the base shear is distributed in a 19-storey building according to the National Building Code, the Unifrm Building Code and the Soviet Code is shown in Figure 8.

Conclusions

The earthquake load provisions of the 1965 National Building Code consider ten of the thirteen basic factors that are generally considered of importance in earthquake engineering design. The manner in which it deals with these factors is in accordance with the knowledge that is presently available, but there is room for further refinement in the treatment ofthese factors when the proper information becomes available. Drift limitation and building separation are two factors not considered by the National Building Code, but Canadian designers in earthquake zones should give them careful thought. The third factor not considered by the National Building Code is the possibility of vertical accelerations acting on a building during an earthquake. This factor is not too important in most cases, since many buidlings have an adequate reserve strength in this direction.

A comparison of the National Building Code and the Uniform Code shows that they give similar earthquake loads, and this means that the application of the National Building Code will provide structures with a comparable earthquake resistance to those in California and Alaska which have with stood severe earthquakes.

References

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(2) "Analytical and Experimental Methods in Engineering Seismology", M. A. Biot, Trans. ASCE 108, 1943, p. 365-408.

(3) "Basic Dynamic Principles of Response of Structures to Earthquake Ground Motions", S. Cherry, Proceedings of the Symposium on Earthquake Engineering, University of British Columbia, September, 1965.

(4) "Limit Design of Structures to Resist Earthquakes", G. W. Housner, Proceedings of the First World Conference on Earthquake Engineering, San Francisco, California, 1960.

(5) Uniform Building Code, 1961 Edition.

(6) "Base Shear in Tall Buildings during Earthquake July 28, 1957, in Mexico City." L. Zeevaert. Proceedings of the Second World Conference on Earthquake Engineering, Japan 1960, Vol. 2, p.983-996.

(7) "There Earthquake Risks in Canada", J. H. Hodgson, Canadian Consulting Engineer, July 1965, p. 42-51.

(8) Climate Information for Building Design in Canada 1965, Supplement No. I to the National Building Code of Canada, Chart 10.

(9) "The Earthquake of 28 July, 1957, in Mexico City", E. Rosenblueth, Proceedings of the Second World Conference on Earthquake Engineering, Japan 1960, Vol. 1, p. 359-379.

(10) "Earthquake Experience in North America, 1950-1959." K.V. Steinbrugge and V.R. Bush, Proceedings of the Second World Conference on Earthquake Engineering, Japan 1960, Vol. 1, p. 381-396.

(11) "Building Code Provision on Torsional Oscillations," J.I. Bustamante and E. Rosenblueth. Proceedings of the Second World Conference on Earthquake Engineering.

(12) "The Niigata Earthquake, 16 June, 1964, and Resulting Damage to Reinforced Concrete Buildings." International Institute of Seismology and Earthquake Engineering Report No. 1, Japan, February, 1965.

(13) "Seismic Shears and Overturning Moments in Buildings", J.I. Bustamante. Proceedings of the Third World Conference on Earthquake Engineering, New Zealand, 1965, Session IV.

FACTORS THAT ARE CONSIDERED IN THE EARTHQUAKE LOAD REGULATIONS OF NINETEEN BUILDING CODES	NUMBER OF CODES THAT CONSIDER THE FACTOR
Calculation of Base Shear	19
Distribution of Base Shear	19
Use of the Building	7
Regional Seismic Zoning	19
Foundation Soil Conditions	12
Type of Structure	6
Vertical Seismic Force	5
Seismic Forces for Attached Structures (parapets, chimneys, towers)	14
Overturning Moment	7
Torsional Forces	6
Drift Limitation	2
Separation of Buildings	7
Allowable Stresses	18

TABLE 1

FACTORS THAT ARE GENERALLY CONSIDERED IN THE EARTHQUAKE REGULATIONS OF BUILDING CODES

NUMBER OF STOREYS	1	5	10	15	20	25	30	35
FORCE AT TOP FLOOR ACCORDING TO 1960 NBC	0.133W	0.133W	0.133W	0.133W	0.133W	0.133W	0.133W	0.133W
FORCE AT TOP FLOOR ACCORDING TO 1965 NBC	0.097W	0.133W	0.090W	0.071W	0.062W	0.054W	0.047W	0.041W
PERCENTAGE OF BASE SHEAR AT TOP FLOOR 1960 NBC	100	41	32	28	27	26	26	25
PERCENTAGE OF BASE SHEAR AT TOP FLOOR 1965 NBC	100	33	18	12	9	8	6	5

TABLE 2

COMPARISON OF THE DISTRIBUTION OF BASE SHEAR ACCORDING TO THE 1960 AND 1965 EDITIONS OF THE NBC

BUILDING	A	B	C	D
Plan Dimensions (ft)	266 x 74	140 x 88	168 x 112	140 x 100
Height (ft)	147	235	430	603
Number of Storeys	10	19	37	47
Vibration Period Perpendicular to Long Axis (sec)	0.69	1.28	4.46	4.65
Vibration Period Perpendicular to Short Axis (sec)	0.59	1.00	3.94	4.65
Assumed Loading of Each Floor (Kip)	1000	1000	1000	1000

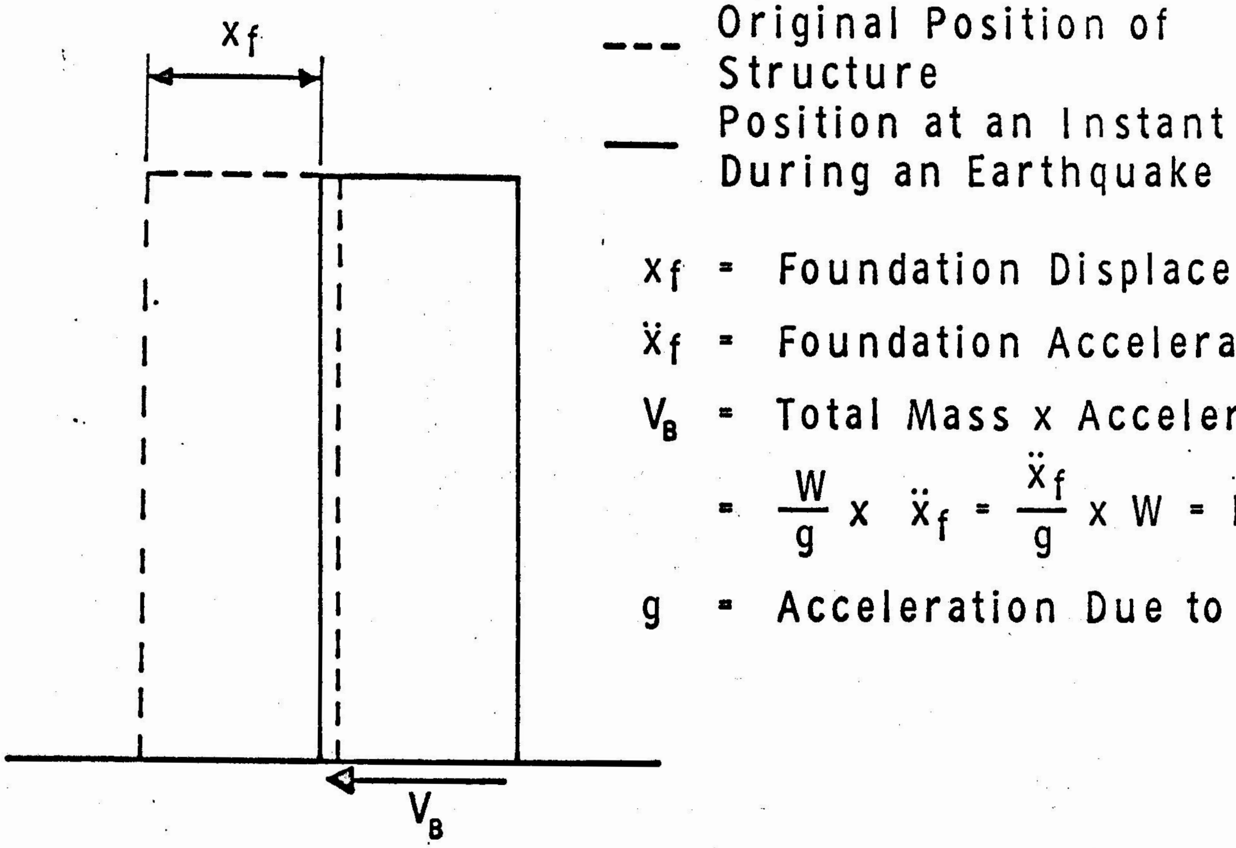
TABLE 3

DETAILS OF FOUR BUILDINGS USED TO COMPARE SOME BUILDING CODES

BUILDING	BUILDING CODE	BASE SHEAR IN THE DIRECTION PERPENDICULAR TO THE LONG AXIS KIPS	BASE SHEAR IN THE DIRECTION PERPENDICULAR TO THE SHORT AXIS KIPS
A 10 STOREYS	NBC 1965	513	513
	Mexican 1963	400	400
	Soviet 1957	1020	1260
	UBC 1961	379	400
B 19 STOREYS	NBC 1965	661	661
	Mexican 1963	760	760
	Soviet 1957	969	1159
	UBC 1961	585	636
C 37 STOREYS	NBC 1965	783	783
	Mexican 1963	1480	1480
	Soviet 1957	1665	1665
	UBC 1961	755	784
D 47 STOREYS	NBC 1965	816	816
	Mexican 1963	1880	1880
	Soviet 1957	2115	2115
	UBC 1961	940	940

TABLE 4

COMPARISON OF THE BASE SHEAR FORCE AS CALCULATED BY FOUR BUILDING CODES FOR AN EARTHQUAKE ZONE 3



x_f = Foundation Displacement

$\ddot{x}_f$ = Foundation Acceleration

V_B = Total Mass x Acceleration

$$= \frac{W}{g} \times \ddot{x}_f = \frac{\ddot{x}_f}{g} \times W = K \times W$$

g = Acceleration Due to Gravity

FIGURE 1A

BASE SHEAR CALCULATION FOR A RIGID BODY

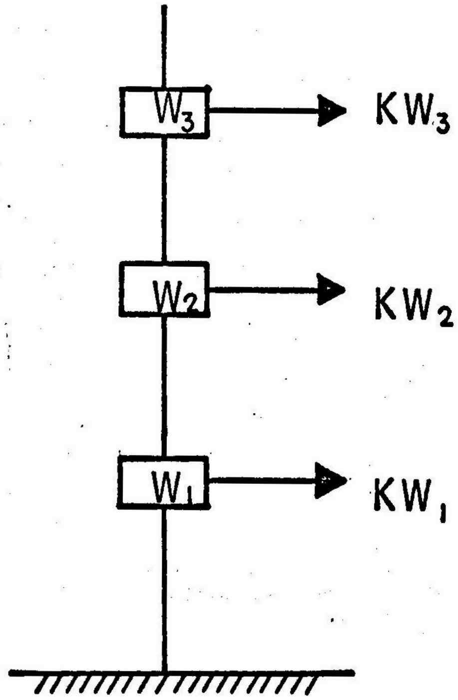


FIGURE 1B

LATERAL FORCES ON A RIGID STRUCTURE, INDUCED BY GROUND MOTION

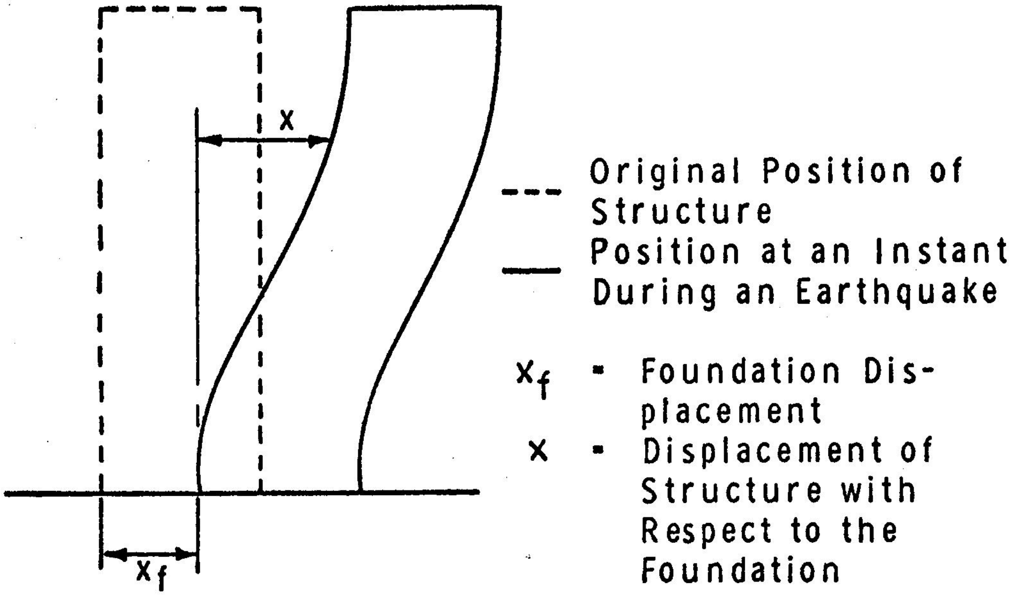


FIGURE 2A FLEXIBLE STRUCTURE

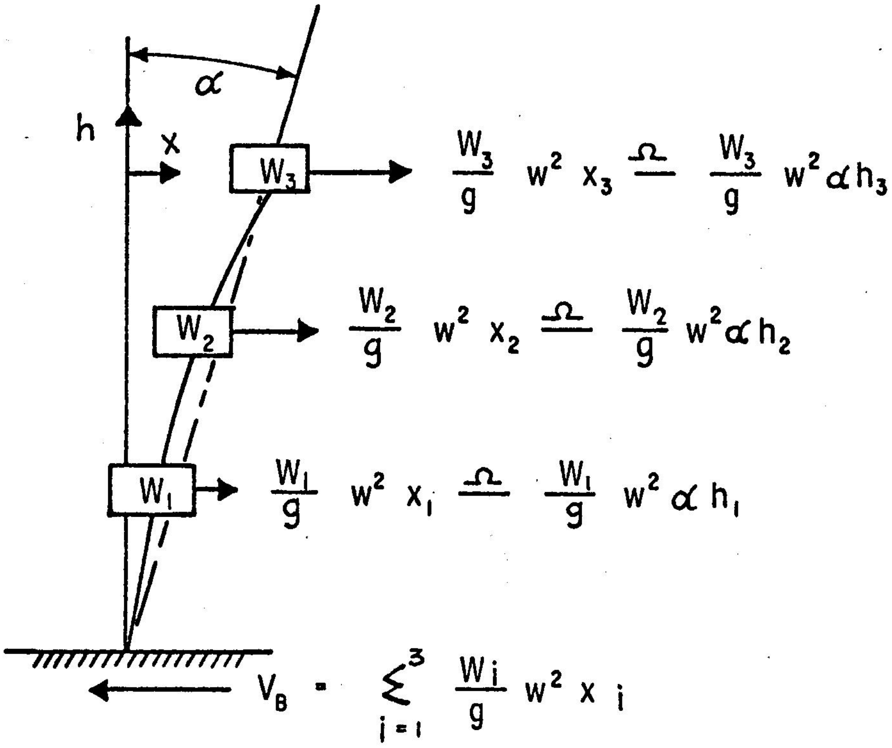


FIGURE 2B

LATERAL FORCES ON A FLEXIBLE STRUCTURE, INDUCED BY GROUND MOTION

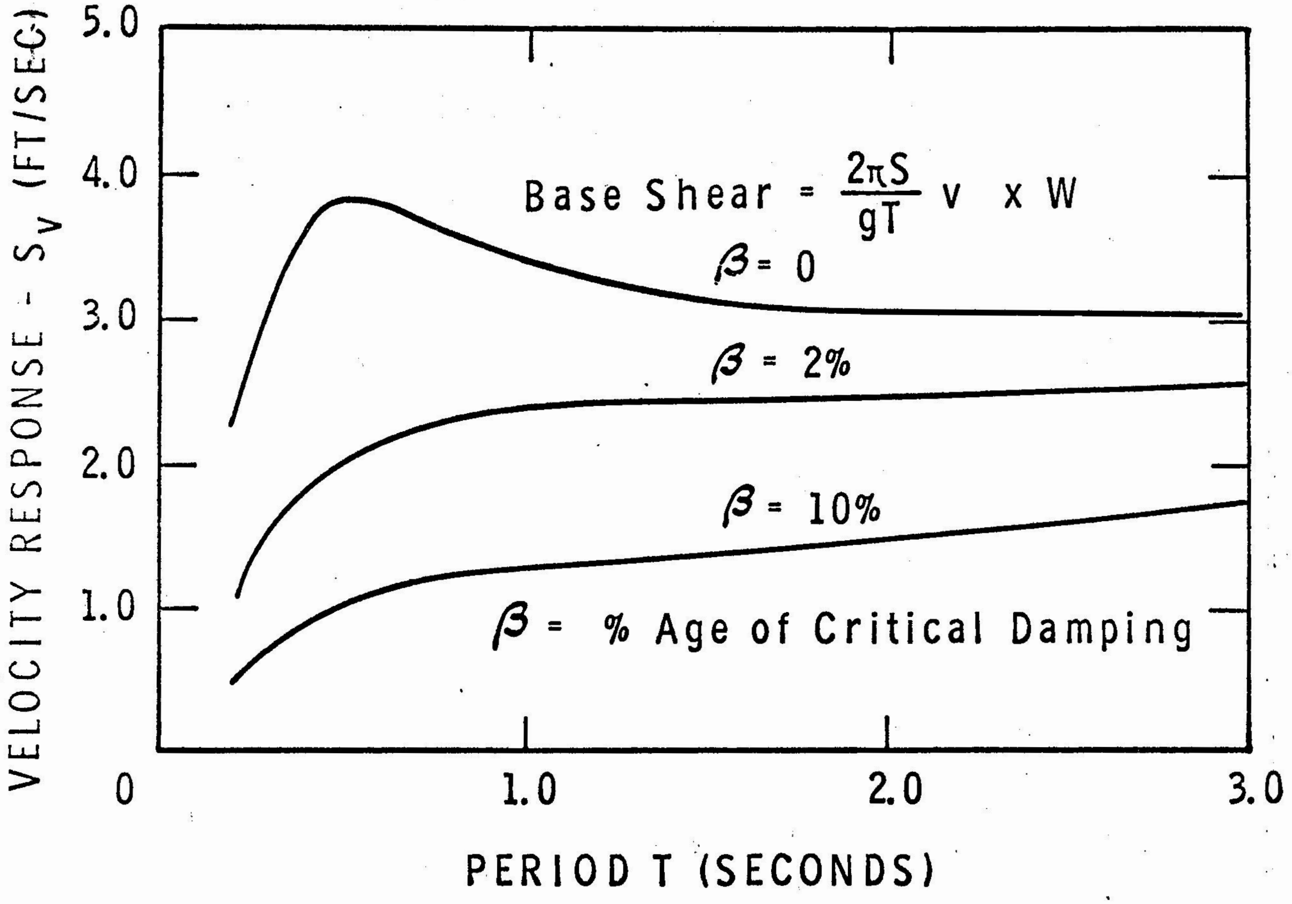


FIGURE 3

VELOCITY REPONSE SPECTRA OF EARTHQUAKES(3)
AFTER HOUSNER

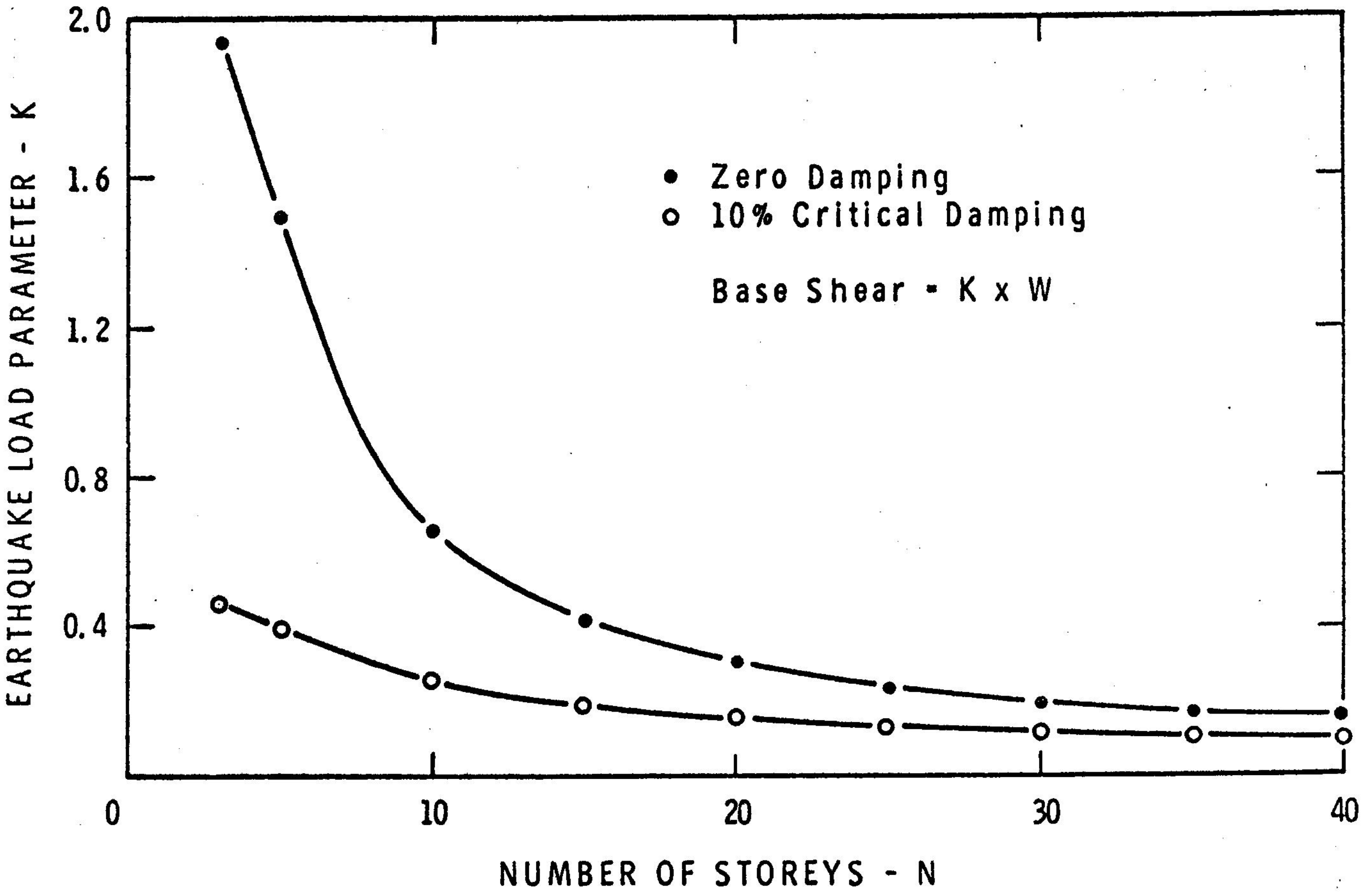


FIGURE 4

EARTHQUAKE LOAD PARAMETER BASED ON HOUSNER'S VELOCITY SPECTRUM RESULTS AND THE ASSUMPTION T = 0.1N

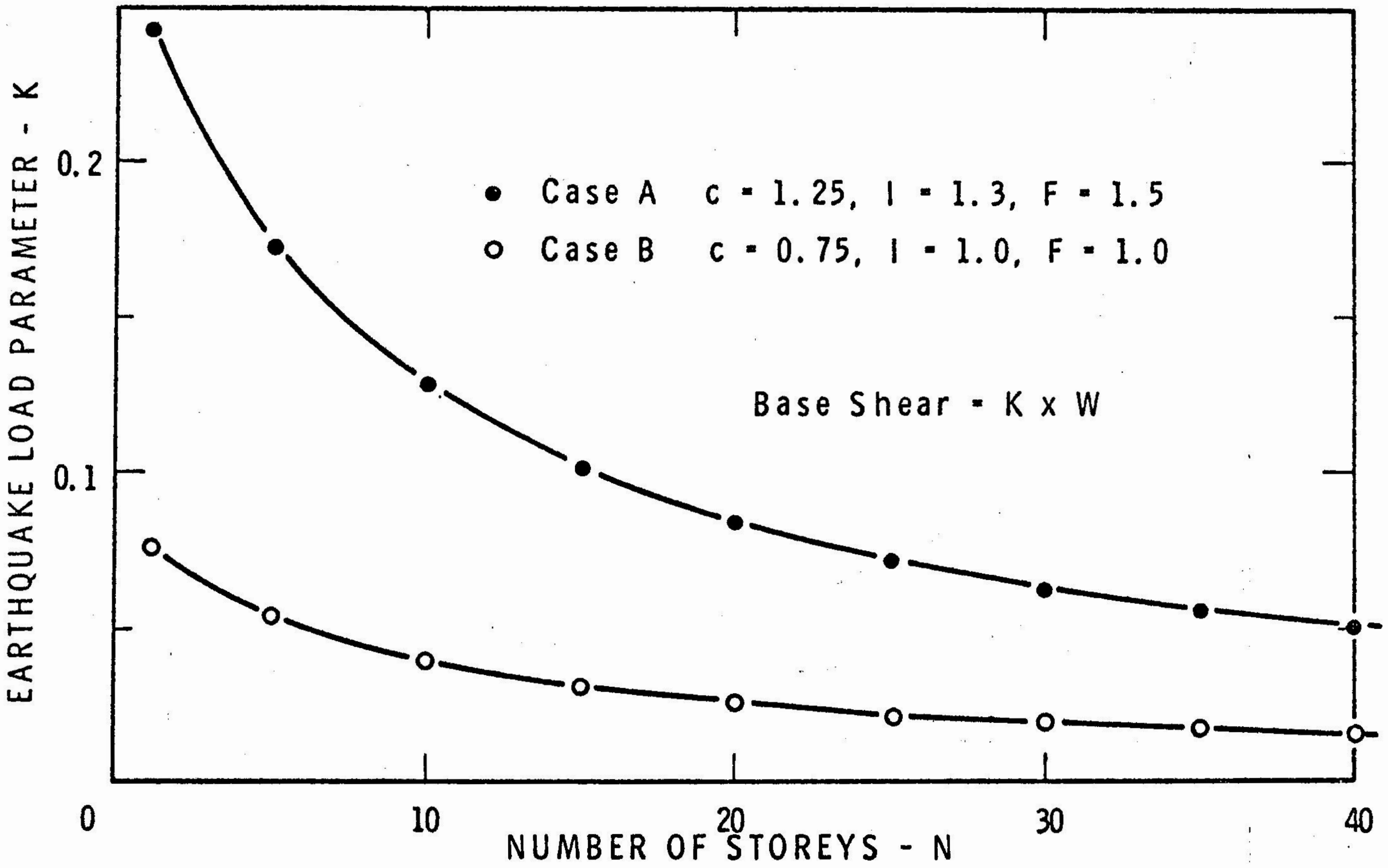


FIGURE 5

NBC EARTHQUAKE LOAD PARAMETER FOR ZONE 3

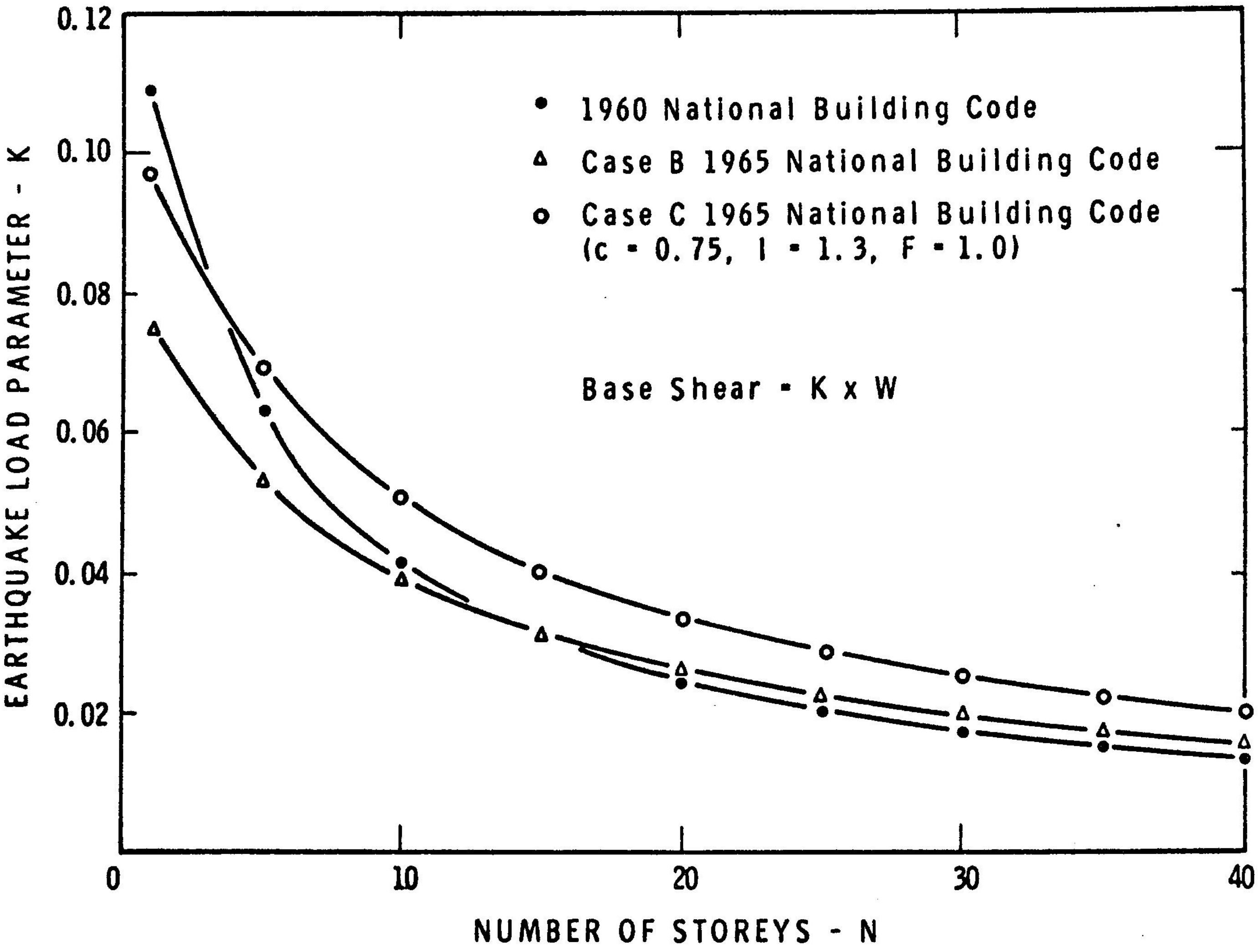
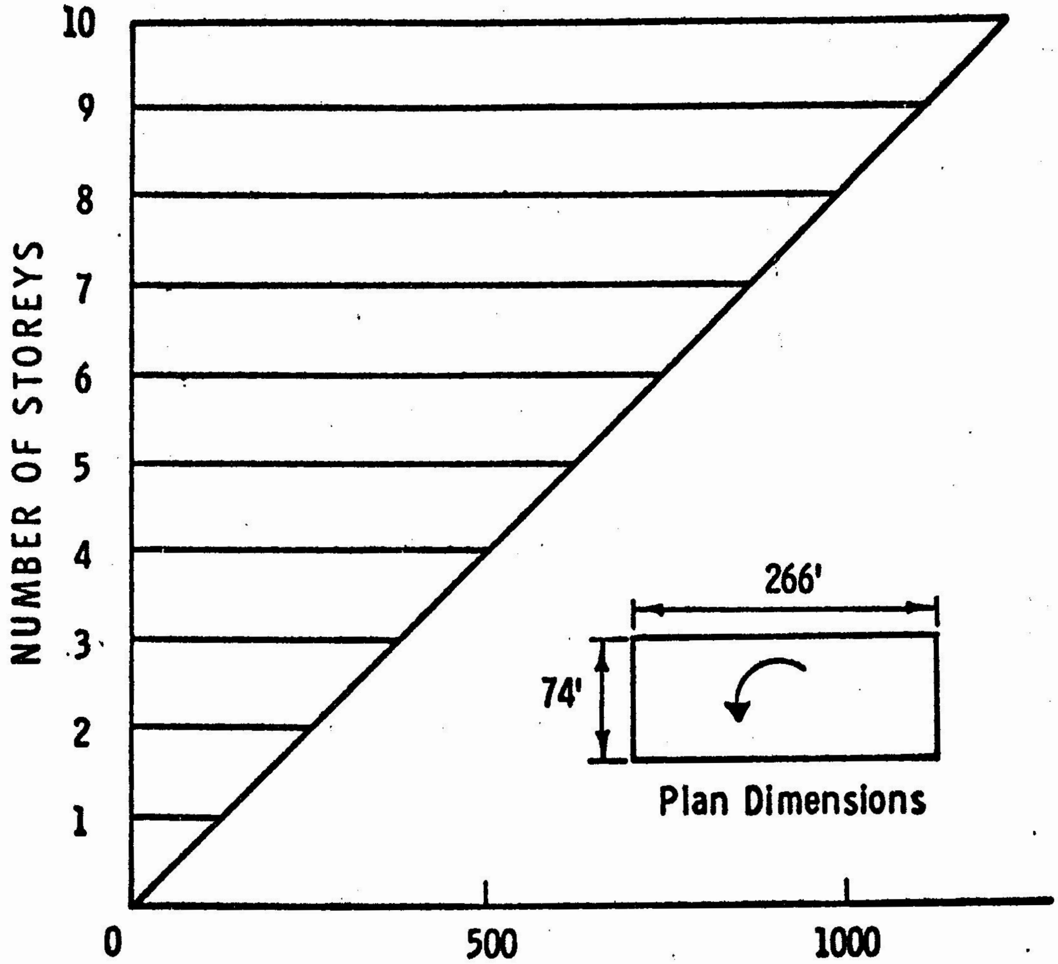
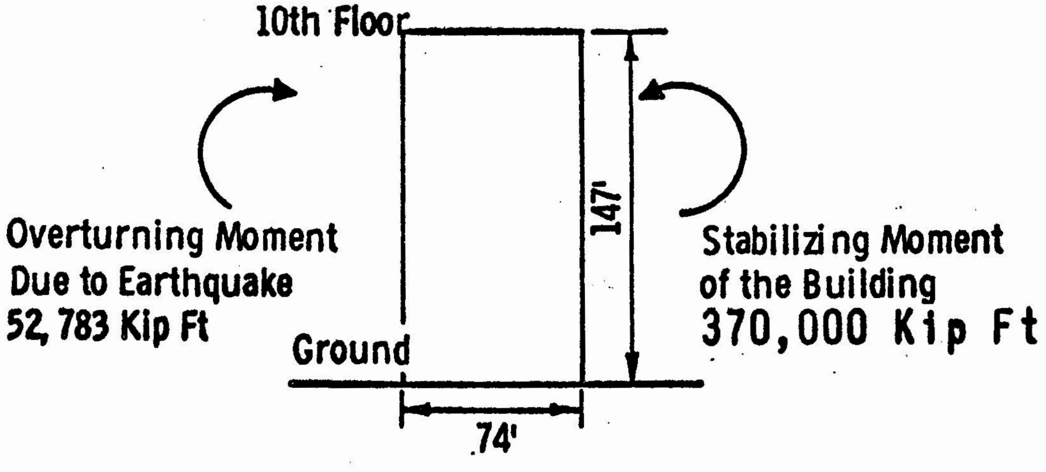


FIGURE 6

COMPARISON OF THE 1960 AND 1965 NBC EARTHQUAKE LOAD REQUIREMENTS FOR ZONE 3



(a) Torsional Moments (Kip Ft)



(b) Overturning Moment

FIGURE 7

TORSIONAL AND OVERTURNING MOMENT FOR A TEN STOREY BUILDING ACCORDING TO THE 1965 NBC

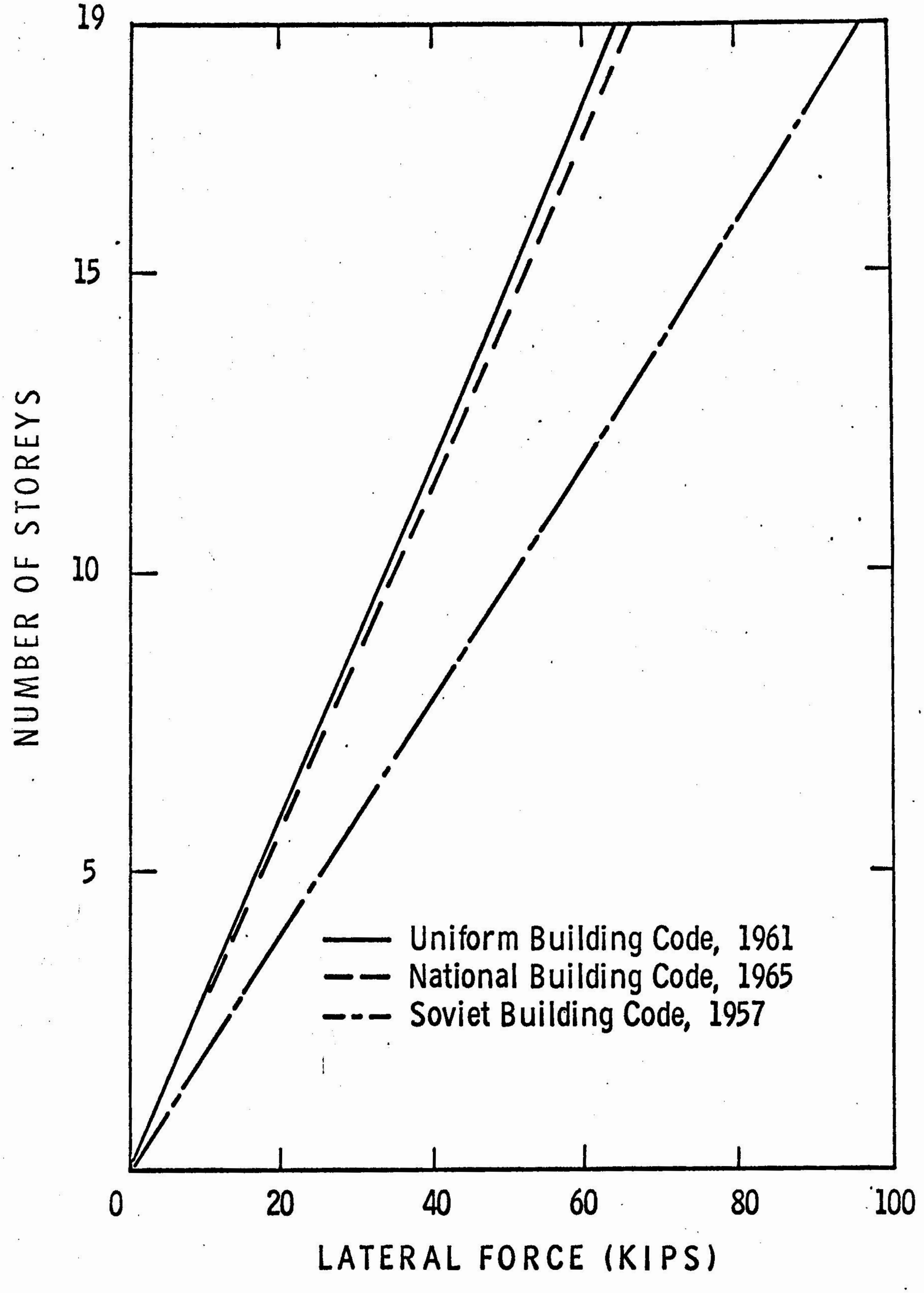


FIGURE 8

DISTRIBUTION OF EARTHQUAKE LATERAL FORCES FOR A 19 STOREY BUILDING WHEN EACH FLOOR LOAD IS 1000 KIPS

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