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COMPARISON OF WIND AND SEISMIC FORCES ON TALL BUILDINGS

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A comprehensive study of the effects of wind and seismic shear forces on tall, rectangular Boston buildings is reported. It has been generally assumed that the Boston Building Code's rather severe wind load requirements provide a significant degree of earthquake protection. The current investigation serves to evaluate this contention. It is well established that seismic forces and story shears become less critical as the height of a building increases. This study reveals that the relative importance of seismic, as compared to wind, forces depends primarily on the weight of the building per square foot of elevation exposed to the design wind pressure. For a typical case the seismic base shear is critical in significant upper portions of the structure for buildings less than about 400 feet in height. For rectangular buildings, seismic forces are relatively more important in the longer directions. Calculations and conclusions are developed for an actual 42-story frame building. A bibliography and graphs are included.

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COMPARISON OF WIND AND SEISMIC FORCES ON TALL BUILDINGS

As the height of a building increases, seismic forces and story shears become less critical as compared to wind forces. This is true because of two effects: (1) Wind pressures increase with height above ground, and (2), the natural period of the building increases with height and consequently the design seismic forces decrease. The purpose of this report is to compare wind and seismic forces, as specified by codes, for typical rectangular buildings.

It is often stated that, even though the Boston Building Code did not previously require design for earthquakes, a significant degree of earthquake protection was provided by the rather severe wind load requirements. The comparisons made herein will serve to evaluate this contention. However, it should be noted that these comparisons deal only with gross shears in the building, and not with other aspects of good seismic design such as provisions to ensure adequate ductility, protection against damage to non-structural items, etc.

Seismic Forces. The total seismic force (or base shear) is given by (UBC).

$$V_E = ZKCW \qquad (1)$$

where,

V_E = total base shear

Z = Zone coefficient

K = ductility factor

C = seismic coefficient $= \dfrac{0.05}{T^{1/3}}$

T = natural period

W = total building weight

For the purpose of this comparison it will be assumed that

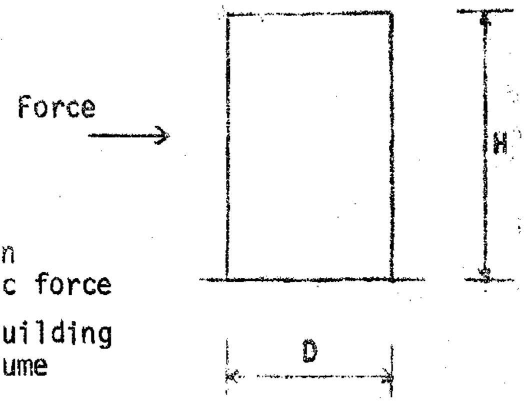
$$T = 0.01H \text{ secs} \qquad (2)$$

where,

H = building height, ft.

This is actually a pretty good assumption for most buildings. The total building weight will be taken as,

$$W = BDHw \quad (3)$$



where,

B = width of building

D = depth of building in direction of seismic force

w = average weight of building in lbs per unit volume

The weight per unit volume, w, varies from a minimum of about 8 lbs/ft^3 for steel frame buildings with light cladding to about 20 lbs/ft^3 for reinforced concrete buildings with granite or precast concrete cladding.

After substituting in Eq. (1) we obtain,

$$V_E = \frac{ZKDBHw}{4.32\ H^{1/3}} \tag{4}$$

Wind Forces. The total wind force (or baseshear) on the building is given by,

$$V_w = HBp \tag{5}$$

where, p = average wind pressure, lbs/ft^2

For the purpose of this comparison, the Boston Wind Code (inland areas) will be used. The specified pressures are as follows:

Height Above Ground	Pressure, lbs/ft^2
0 - 200'	20
200 - 300'	25
300 - 400'	30
400 - 500'	35
500 - 600'	40
600 - 700'	45
700 - 800'	50
800 - 900'	55
900 -1000'	60

Base Shear Ratio. Using Eqs. (4) and (5), the ratio of wind to seismic base shear is given by,

$$\frac{V_W}{V_E} = \frac{4.32p\ H^{1/3}}{ZK\ (Dw)} \qquad (6)$$

For a given building height, building type, and location, the important parameter becomes Dw, the weight of the building per square foot of elevation area looking in the direction of the seismic or wind force.

Eq. (6) is plotted in Fig. 1 where the ratio of wind to seismic base shear is plotted against building height for three values of Dw. The curves are for ZK = 1.5 (e.g., Zone II (Z = 0.5) and K = 1.0). It may be observed that the parameter Dw has a great influence. Dw = 1000 may be a typical value (e.g., D = 100' and w = 10 lbs/ft^3). For this case, the seismic base shear is larger than the wind shear only for buildings less than 200 ft. in height.

An important observation to be made from this comparison is that, for a rectangular building, earthquake is relatively more important in the long direction, i.e., the value of Dw is larger. In other words, the weight of the building per unit area of elevation is larger as compared to the wind pressure. In framed buildings designed for wind, columns are usually oriented so that their strong plane in bending parallels the shorter dimensions of the building. However, for seismic design, the required strength of the columns is essentially the same in both directions.

Shear Ratios at Other Elevations. In the upper stories of a tall building the seismic story shears are relatively more important. This is true because the seismic forces are assumed to increase linearly from zero at ground level to a maximum at the top of the building. Wind forces also increase with height, but not as much as the seismic forces.

To demonstrate, Figure 1 also shows the wind to seismic shear ratio at three-quarters of the building height. Designating the shears at this point by V_E' and V_W', we find,

$$V_E' = \frac{7}{16} V_E$$

$$V_W' = \frac{p'}{p} \cdot \frac{V_W}{4}$$

where p' = the average wind pressure in the upper one-quarter of the building. In computing V_E', the concentrated seismic force at the top of the building, as specified by the UBC, has been ignored. This has a significant effect only if H/D is greater than 3 and even then only in a few of the upper-most stories.

In Fig. 1 it may be seen that the seismic shear is relatively much more important at the three-quarters height of the building. For example, if Dw = 1000 the seismic shear is critical for buildings less than 370 ft. in height (as compared to 200 ft when base shear is considered).

Comparison for an Actual Building. To illustrate further, Fig. 2 compares the wind and seismic shears for an actual building over its entire height. The building is 42 stories high, rectangular in plan and is essentially a rigid frame structure. Therefore, the ductility factor, K, is taken as 0.67. The natural periods in the two horizontal directions were actually measured in the field. The density of the building was computed based on the design drawings.

It may be observed that for Zone II ($Z = \frac{1}{2}$) the wind shear is much greater than seismic shear over the full height of the building, and in both directions, except in the top one or two stories (the concentrated seismic force at the top has been included here). Even for Zone III ($Z = 1$) loading, the seismic shear is considerably less in the short direction and essentially the same as the wind shear in the long direction.

Summary (1) The relative importance of seismic as compared to wind forces depends primarily on the weight of the building per square foot of elevation area exposed to the design wind pressure. (2) For a typical case, Dw = 1000 lbs/ft^2, the seismic base shear is critical only for buildings less than 200 ft. in height, but the seismic shear is critical in significant upper portions of the structure for buildings less than about 400 ft in height. (3) For buildings rectangular in plan, seismic forces are relatively more important in the longer direction. (4) Calculations for an actual 42-story frame building indicate that Zone II seismic shears are not critical, and that Zone III seismic shears are less in the shorter direction but essentially the same as the wind shear in the longer direction.

List of Internal Study Reports

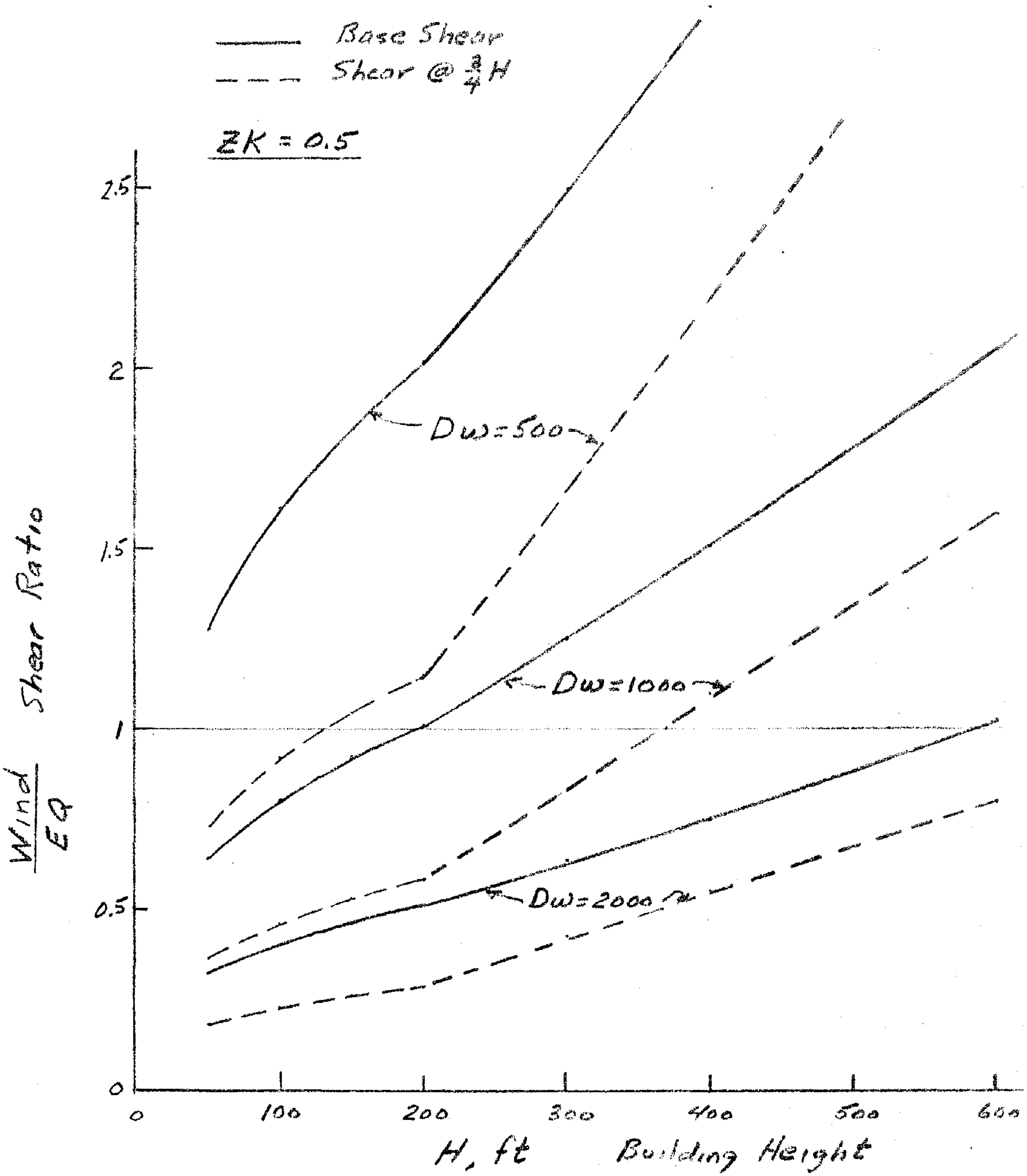
1. R.V. Whitman, "Preliminary Work Plans and Schedules," August, 1971.

2. E.H. Vanmarcke and R.V. Whitman, "Background for Preliminary Expected Future Loss Computations," October, 1971.

3. P.J. Trudeau, "Identification of Typical Soil Profiles in the Boston Basin Area," November, 1971.

4. J.M. Biggs, "Comparison of Wind and Seismic Forces on Tall Buildings."

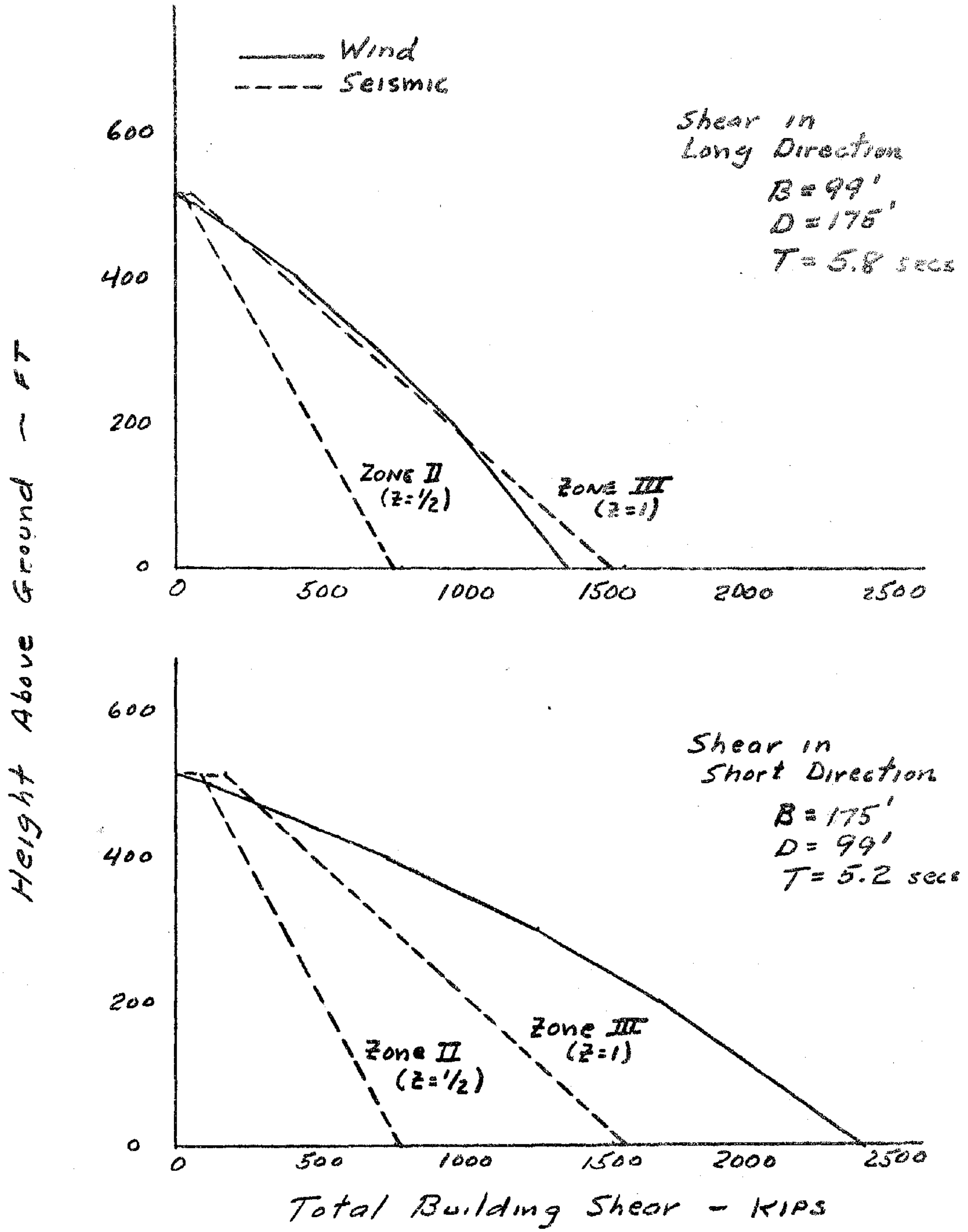
FIG. 1



D = Building depth in shear direction, ft.
w = Building weight, lb/ft^3

Based on Boston Wind Code (Inland)

FIG. 2



Wind and EQ Shears
Wind - Boston Wind Code
EQ - UBC, K = 0.67

Building X
$\omega = 9.04\ \text{lb}/\text{ft}^3$