THEORETICAL CONSIDERATION ON OVERTURNING OF BODIES BY EARTHQUAKE MOTIONS AND FIELD SURVEY OF 1978 OFF MIYAGI PREFECTURE EARTHQUAKE

by

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SUMMARY

This paper introduces the theoretical consideration on overturning of bodies by earthquake motions and derives the simple formula to estimate the response velocity from the dimension of the body overturned. This formula was applied to the field survey of furniture overturned at the time of 1978 OFF MIYAGI PREFECTURE EARTHQUAKE in Japan and the velocity distribution map was obtained. This map shows the overturning of furniture depends much on the soil condition as well as the distance from the epicenter.

1. THEORETICAL CONSIDERATION

Overturning of bodies has been one of the most simple and noticeable phenomena during earthquake motions. Many researchers have analysed the mechanism of overturning and attemped to estimate the intensity of the earthquake by this phenomenon, but the exact solution cannot be obtained yet.

Most fundamental consideration on overturning is that the acceleration can be deduced from the breadth-height-ratio of the column multiplied by the acceleration of gravity. Namely, the acceleration, a, which will initiate the rocking motion to the column is given by the following formula.

$$a = \frac{B}{H} g \qquad (1)$$

where, B and H are the breadth and the height of the column, respectively, and g is the acceleration of gravity. But the acceleration which exceeds the value given by formula (1) does not always overturn the body, because the formula only indicates the necessary condition for rocking. Furthermore, it is a well-known phenomenon that the larger the body is, the more difficult to overturn it, in case the breadth-height-ratio of the body remains constant. But formula (1) is only depending on the breadth-height-ratio and not on the dimension. In order to explain this phenomenon, let us suppose that the body has the velocity, v, during earthquake motions and suddenly the rectilinear motion changes to rocking motion. From the conservation of the momentum around the edge, O, we can have (See Fig. 1)

$$\frac{1}{2} H M v = I_o \omega \qquad (2)$$

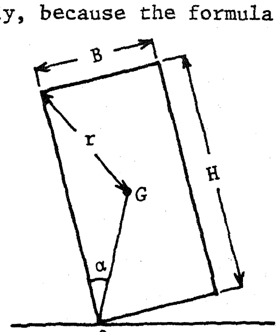

Fig. 1 Rocking of a Column

I. Head, The First Earthquake Engineering Division, International Institute of Seismology and Earthquake Engineering, Building Research Institute, Ministry of Construction, Japanese Government where, M is the mass of the body, I_o is the moment of inertia around O, ω is the angular velocity of the body. In case of the rectangular column,

$$I_o = \frac{4}{3} M r^2 \quad (3)$$

where, r is the length from the center of gravity to O. If we assume $\frac{H}{2} \simeq r$ for slender columns, we have from formulae (2) and (3),

$$\omega = \frac{3v}{4r} \quad (4)$$

Then the kinetic energy, KE, at the beginning of rocking motion is,

$$KE = \frac{1}{2} I_o \omega^2$$

$$= \frac{3}{8} M v^2 \quad (5)$$

The increment of potential energy, PE, when the center of gravity reaches the perpendicular line of O is,

$$PE = \frac{M g r \alpha^2}{2} \quad (6)$$

From formulae (5), (6) and the relation $r\alpha \simeq \frac{B}{2}$

$$v = \sqrt{\frac{2 g B \alpha}{3}} \quad (7)$$

If we use the units of centimeters and seconds for length and time, respecttively, and the relation $\alpha \simeq \frac{B}{H}$, formula (7) will be,

$$v = 25.6 \frac{B}{\sqrt{H}} \quad (8)$$

From formula (8), it is possible to estimate the response velocity of the body overturned during earthquake motions. The formula (8) also shows that the velocity to overturn the body is proportional to the square root of the dimention, in case the breadth-height-ratio remains constant.

2. FIELD SURVEY

1978 OFF MIYAGI PREFECTURE EARTHQUAKE caused extensive damage in Sendai City and its vicinities. We surveyed the overturning of furniture, interviewing the inhabitants concerning the following items.

(1) Type of furniture overturned
(2) Dimension of the furniture
(3) Direction of the overturning
(4) Floor number where the furniture was placed
(5) Outline of the building where the furniture was placed

Most of the buildings surveyed were common wooden residential houses constructed by the conventional Japanese post and beam construction. The total number of the buildings surveyed was 138; 130 of two story wooden houses, 2 of one story wooden houses, 5 of medium and low-rise reinforced concrete buildings and one of high-rise steel frame buildings.

The result of the survey is shown in Fig. 2, where (a)◉ , (b)◎ , (c)● , (d)○ and (e) + show the buildings where the response velocity of furniture at 1st floor was (a) more than 80 kine (cm/sec), (b) from 80 to 60 kine, (c) from 60 to 40 kine, (d) from 40 to 20 kine and (e) less than 20 kine, respectively. The velocity was determined by the formula (8) and the magnification factor of the 2nd floor velocity to the 1st floor was assumed to be 2.0. From Fig. 2, the followings can be seen:

i) In western part of Sendai City, where several reinforced concrete buildings collapsed, much furniture overturned and the velocity of 1st floor was more than 80 kine, whereas in the eastern part of Sendai City, almost no furniture overturned and the velocity was less than 20 kine.

ii) Dotted part of Fig. 2 shows the area where the surface of the ground is covered by alluvium, and the velocity of this area was very high compared to the other area.

iii) The area where is 120 km apart from the epicenter, almost no furniture overturned. But along the Abukuma River, the overturning was observed up to Shiroishi City and Fukushima City which are more than 120 km from epicenter. This is because of the alluvium deposit along the river.

iv) Differences of overturning phenomena among the types of buildings is not clearly observed, because of the lack of data concerning other types of buildings than the wooden ones.

v) In western part of Sendai City where no furniture overturned in low-rise buildings, however much furniture overturned in high-rise buildings especially in upper floors. We should be careful for the fact that high-rise buildings will have less base shear than low-rise buildings, but the response velocity will be considerably magnified and overturning of furniture may harm human lives especially at upper floors of high-rise buildings.

3. CONCLUDING REMARKS

The overturning of bodies is caused not only by the acceleration but also by the velocity. In fact, the velocity has more influence than the acceleration. Therefore the maximum response velocity can be estimated from the dimension of columns overturned during earthquake motions, using a simple formula derived in this paper. The velocity distribution map can be obtained, if we survey the overturning of furniture and apply this formula to them. The application of this formula at the time of 1978 OFF MIYAGI PREFECTURE EARTHQUAKE shows that the overturning of furniture depends much on the soil condition as well as the distance from epicenter and the furniture overturns easily at upper floors of high rise buildings.

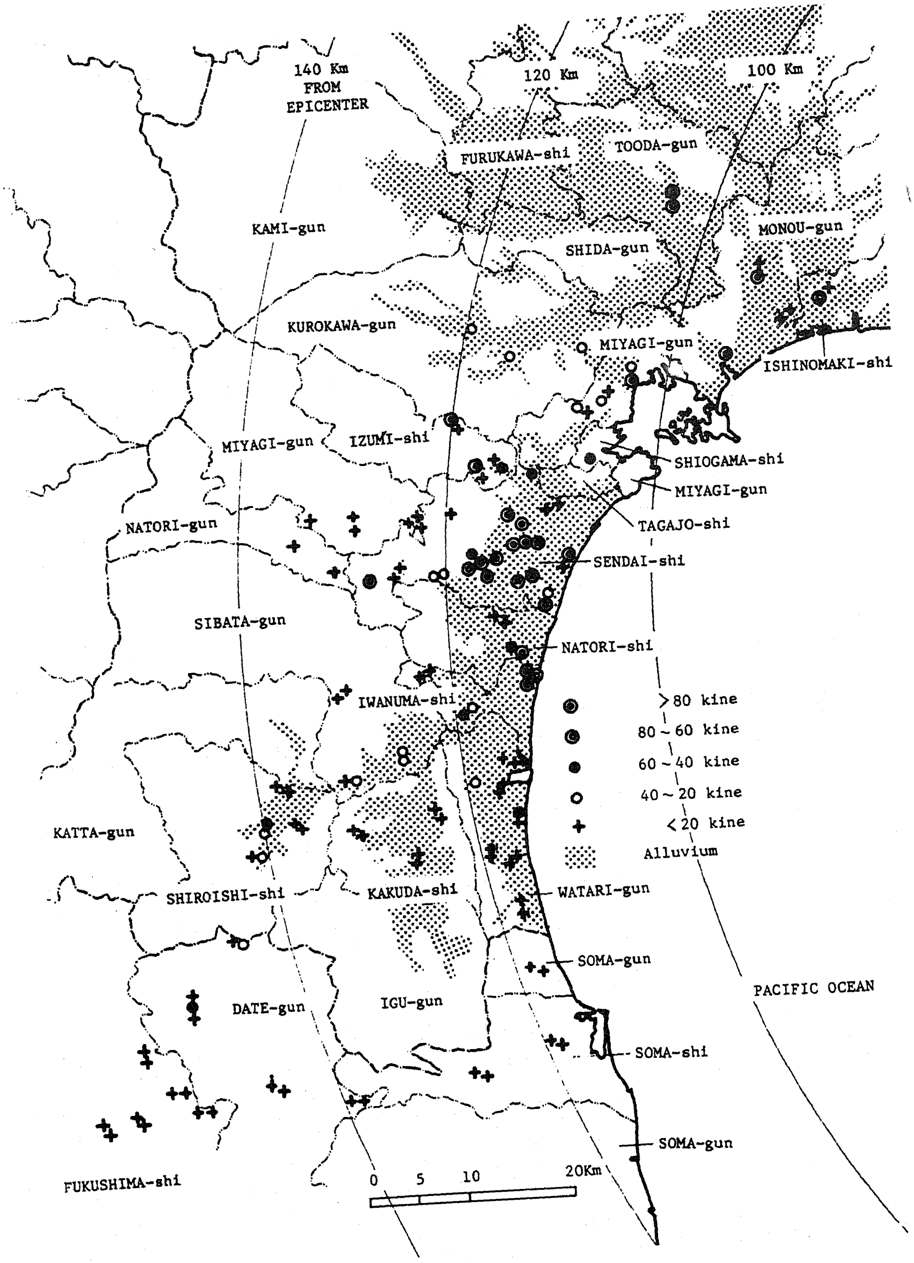

Fig. 2 Velocity Distribution Estimated by Overturning of Furniture in 1978 OFF MIYAGI PREFECTURE EARTHQUAKE