often more damage resistant than similar structures of conventional forms. The form of the openings in a masonry wall has a significant influence in the pattern of stress concentration and in the seismic behavior of that wall. Small openings with round corners seem to be better than those with sharp corners.

## 5 - BRITTLE VS. DUCTILE DESIGN PHILOSOPHIES

Many traditional assumptions and approximations carried over from the design of conventional ductile structures are not applicable to brittle-type structures. The most important one is the assumption of the redistribution of forces due to the yielding of the resisting member, which is a fundamental assumption in plastic design and in seismic design of ductile structures. This assumption is not valid for brittle-type structures, and many simplifications and rules of thumb based on ductile bahavior must be revised. In ductile structures the maximum load that a parallel row of resisting elements can carry is usually equal to the sum of the ultimate resistance of all these elements. The maximum load capacity of a system of a row of brittle resisting elements is usually less than the sum of the ultimate resistance of all the elements because the overloaded members fail in a sudden brittle mode and all members would rarely reach their ultimate state all at the same time. Sometimes the brittle resisting elements fail in a successive mode similar to the so-called unbuttoning phenomenon which occurs in long rows of rivets and bolts. Therefore;

a) The loads in members of brittle-type structures should be obtained by an accurate elastic analysis.

b) Any change in the stiffeness of members resulting from the action of non-structural elements which may change the distribution of the lateral loads in the brittle elements of the structure from their initial design value must be avoided, or their action must be included by an elastic analysis.

c) The structural design of a building with a brittle component is optimum if the buildings fail by simultaneous failure of the brittle components under the critical load condition (the so-called one-hoss-shay design philosophy), but remains elastic under less than critical load conditions.

## 6 - DETERMINATION OF SUITABLE DESIGN LOAD FACTORS

In order to obtain the same probability of damage or failure for brittle and ductile structures under similar earthquakes a much higher seismic load factor should be used in the design of brittle-type structures. Design load factors should depend upon the energy absorption and ductility characteristics of the resisting elements. Establishing a quantitative relationship between the ductility of a structural system and its design load factor needs further research. Figs. 1 & 2 show a proposed hypothetical method for the establishment of this relationship. In Fig. 1 three design base shears are shown: 1) the elastic base shear ($V_e = C_e W$) representing the effect of minor earthquakes which should not cause any structural or non-structural damage. $C_e$ is the elastic base-shear coefficient and W is the seismic tributary gravity load; under this base shear the working stresses in all parts of the structure shall remain within elastic range, 2) the yield base shear ($V_y = C_y W$) representing the effect of moderate earthquakes which should not cause any structural damage. $C_y$ is the yield base-shear coefficient. Under this base-shear the stresses in all parts of the structure shall not exceed the yield value. Every structure must also be designed ultimately to resist the collapse load represented by collapse base-shear ($V_c = KC_cW$). K is the load reduction factor and is a function of the ductility of the structures ($\alpha = \Delta/\Delta_y$) and its fundamental period of vibration (T) as shown hypothetically in Fig. 2. $C_c$ is the collapse base-shear coefficient. For brittle structures with $\alpha$ equal to one, K is equal to one. As $\alpha$ and T of the structure increase the required K will decrease and a smaller collapse base-shear is required. As an example, for brittle structures without a vertical load-carrying skeleton and without a ductile lateral-load resisting system K is equal to one and the collapse base shear is $V_c = C_cW$. Due to brittleness the stresses should not exceed the yield limit under this high base-shear. Similarly for brittle structures with vertical load-carrying skeletons and lateral-load resisting systems having $\alpha = 4.0$ and $T = 0.4$ from Fig. 2, $K = 0.66$ and $V_c = 0.66\ C_cW$.

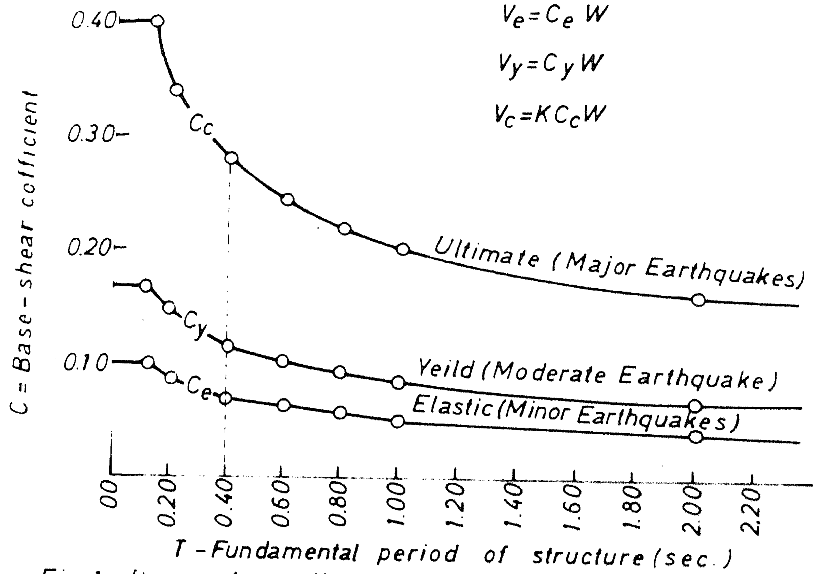

Fig. 1: Base-shear diagram for various earthquakes

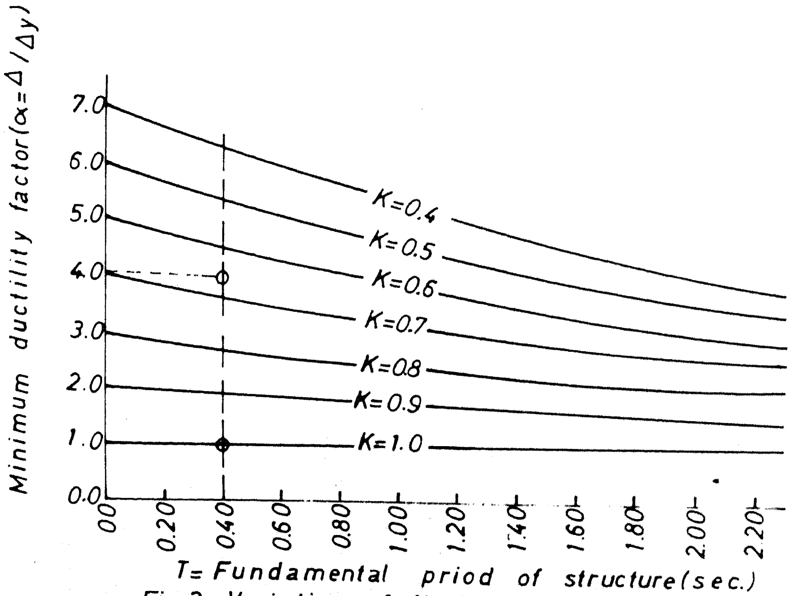

Fig. 2 : Variation of K due to ductility factor