Seismic Evaluation and Economical Strengthening of Reinforced Concrete Buildings

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The handbook, entitled Standard for Evaluation of Seismic Capacity of Existing RC Buildings, provides a method of expressing the seismic performance for existing reinforced concrete buildings through a continuous index and judges their seismic safety. The Standard for seismic evaluation in Japan is outlined in the following section.

Seismic Performance Index

The Standard provides an approximated calculation method for the seismic performance of buildings in terms of two indexes, the seismic index of structural elements, IS, and the seismic index of nonstructural elements, IN. The Standard was developed for the purpose of evaluating a large number of buildings in the shortest possible time. Therefore, while referring to other already-proposed seismic design and evaluation methods, the method was simplified as much as possible without losing the essence, so that three levels of calculation methods are provided from simple to sophisticated one called as the first, second and third screening levels.

In the Standard, the seismic performance index of a building is expressed by the Is-Index for each story and each direction, as shown in Eq. (1):

$$I_S = E_0 . S_D . T \qquad (1)$$

where:

E_0 = Basic seismic index of structure.

S_D = Irregularity index.

T = Time index.

E_0 is a basic structural index calculated from strength index (C), ductility index (F), and story index (Φ), C-Index denotes the lateral strength of the buildings in terms of shear force coefficient. F-Index denotes the ductility index of the building ranging from 0.8 (most brittle) to 3.2 (most ductile), depending on the sectional properties such as bar arrangement, member proportion, shear-to-flexural-strength ratio etc. Φ is a modification factor to allow for the mode shape of the response along the building height. Basically in the Standard, a

simple formula of $\Phi=(n+1)/(n+i)$ is employed for the i-th story level of an n-storied building by assuming straight mode and uniform mass distribution.

S_D- and T-Index are reduction factors to allow for the disadvantages in the seismic performance of structures. S_D-Index, basically ranging from 0.4 to 1.0, is for modifying E_0-Index due to unbalanced distribution of stiffness both in the horizontal plane and along the height of the structure, resulting from irregularity and complexity of structural configuration. T-Index, ranging from 0.5 to 1.0, is employed to allow for the deterioration of strength and ductility due to age after construction, fire and uneven settlement of foundation.

The first level procedure is the simplest but most conservative since only the sectional areas of columns and walls and concrete strength are considered to calculate the strength, and the inelastic deformability is neglected. The ductility index is simply assumed as 1.0 in a case without extremely brittle columns or 0.8 otherwise.

In the second and third level procedures, ultimate lateral load carrying capacity of vertical members or frames are evaluated using material and sectional properties together with reinforcing details based on the field inspections and structural drawings. The basic index E0 is defined in the following ways:

Ductility-dominant basic seismic index of structure

$$E_0 = (n+1)/(n+i)\ (E^2_1 + E^2_2 + E^2_3) \qquad (2)$$

$$E_i = C_i \times F_i$$

C_1 , C_2 , C_3 = The strength index C of the first, second and third group

F_1 , F_2 , F_3 = The ductility index F of the first, second and third group

$$E_0 = (n+1)/(n+i)\ [C_1 + \sum \alpha_j C_j].\ F_1 \qquad (3)$$

where:

α_j = Effective strength factor in the j-th group elements at the ultimate deformation R1 corresponding to the first group elements (ductility index of F_1)

The basic index of Eq. (2) and Eq. (3) denotes the earthquake intensity when the inter-story drift response would attain its limit state. The second screening considers only the vertical members, such as columns and walls, while the third screening considers beams as well. The methods or Eqs. for evaluating strength and deformability of the members are prescribed in the standard.

The elements are classified into three groups at the maximum for calculating ductility-dominant basic seismic index. First group is for brittle element, third group is for ductile element, and second group is medium.

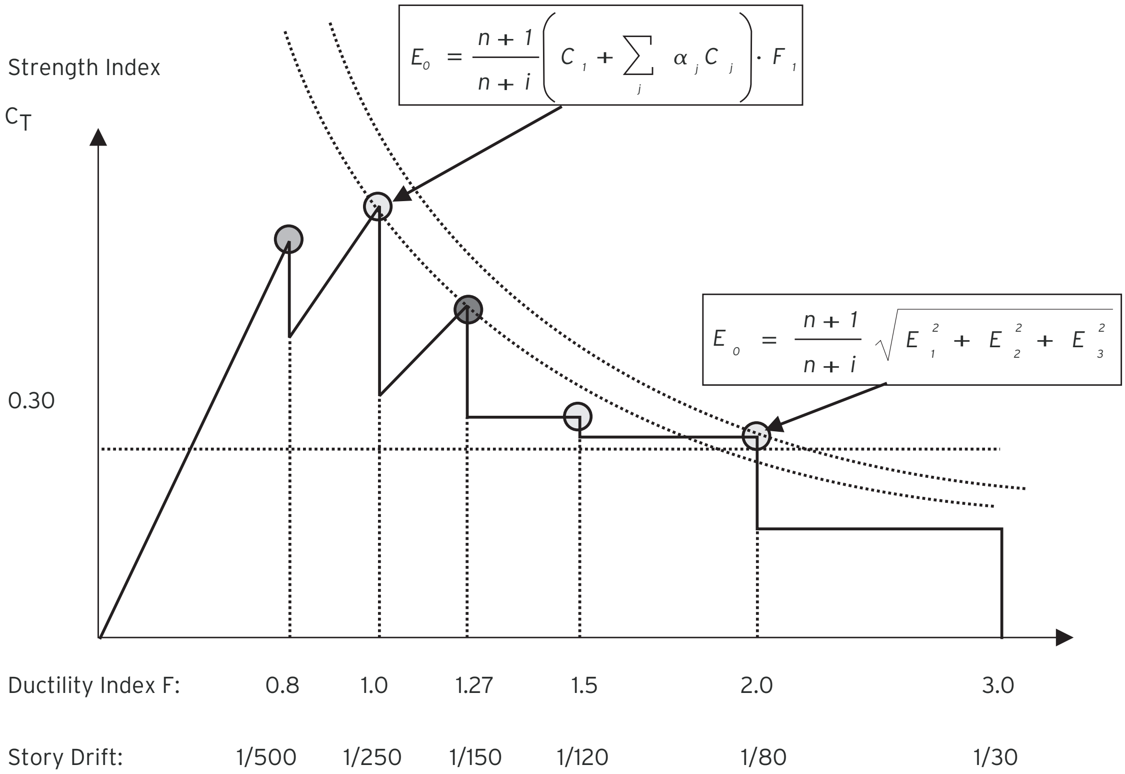

Fig. 1 Idealized relations of lateral strength and ductility for seismic index

The ductility index as the boundary of groups can be chosen to make E_0 the biggest. Here, the ductility index of all group elements must be bigger than 1.0, and less than that in ultimate deformation of structure.

The load deformation relations in i-th story is calculated and idealized as shown in Fig. 1. The relations are idealized as a system consisting of three levels of ductility indices F_1, F_2 and F_3. The Eqs. (2) and (3) provide the earthquake intensities corresponding to the limit states at the ductility levels of F3 and F 1, respectively. Therefore, the basic index may generally be taken as either lager one of above two. The Eq. (2) gives higher values for systems mostly with ductile members, while the Eq. (3) gives higher values mostly for systems with non-ductile members.

However, to consider the value given by the Eq. (2), it should be confirmed that brittle failure of some columns would not induce partial collapse of the structure at a smaller deformability than F_3 level, otherwise the structural limit state should be defined at the deformability that the partial collapse would occur, within which the index shall be calculated by Eq. (2). The method of calculating such deformation is also given in the Standard. The detailed calculation method for evaluating the ductility of partial collapse is clearly prescribed in the recent 2001 version. This is achieved by the judgment of the "second-class prime elements": in case a column could not carry the axial load beyond the ductility level, even by considering redistribution of the gravity axial load to the adjacent members, the column is judged as "the second-class prime element" and the associated deformation of partial collapse is defined as the limit state. The ductility index is defined as the deformation where the lateral resistance starts to decay. In the former version, the axial capacity of column beyond the defined ductility level is assumed to be zero, namely that the axial capacity is lost simultaneously with the shear failure before or after flexural yielding. However, the axial load capacity could be maintained beyond the defined ductility level. In the 2001 version, the residual axial load capacity beyond the defined ductility level may be account for the judgment of collapse. The calculation method for the residual axial capacity is given in the Standard. The members' capacities required for redistribution, such as the connecting beam strengths, shall be checked. The axial capacity of the adjacent members shall also be checked. If the axial load can be sustained by the residual capacity or adjacent elements, the column is not judged as not "the second-class prime element," but as "the third-class element," and the limit state may be taken as larger than the defined ductility level.

By adopting this standard we can have better seismic evaluation and economical strengthening of Reinforced Concrete buildings.