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ANALYSIS OF EARTHQUAKE RESISTANCE OF A MULTI-STORY FRAME BUILDING BASED ON BEST PRACTICES, TAKING INTO ACCOUNT CONSTRUCTIVE MEASURES

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Annotation: *The article discusses seismic analysis methods for structural engineering, focusing on linear and nonlinear approaches. It covers the mathematical modeling of structures, material properties, and the application of seismic forces. Prescribed displacements and their significance in structural design are also addressed.*

Annotatsiya: *Maqolada chiziqli va chiziqli bo'lmagan yondashuvlarga e'tibor qaratgan holda qurilishni loyihalashda seysmik tahlil usullari ko'rib chiqiladi. U konstruksiyalarni matematik modellashtirish, material xossalari va seysmik yuklarni qo'llashni o'z ichiga oladi. Belgilangan ko'chishlar va ularning konstruktiv dizayndagi ahamiyati ham muhokama qilinadi.*

Аннотация: *Статья рассматривает методы сейсмического анализа в строительном проектировании, с акцентом на линейные и нелинейные подходы. В ней рассматриваются математическое моделирование структур, свойства материалов и применение сейсмических нагрузок. Также обсуждаются предписанные перемещения и их значение в конструктивном проектировании.*

Keywords: *Analysis, linear, nonlinear, modeling, displacement.*

Kalit so'zlar: *Tahlil, chiziqli, chiziqli bo'lmagan, modellashtirish, ko'chish.*

Ключевые слова: *Анализ, линейный, нелинейный, моделирование, перемещение.*

Introduction. Seismic events, though unpredictable in occurrence, have the potential to inflict substantial damage on buildings and infrastructure. In regions susceptible to seismic activity, the structural integrity of buildings is of paramount importance. This article delves into the critical aspects of seismic resistance analysis and modeling for frame buildings, with a particular focus on utilizing Eurocode examples. The main goal of this paper is to provide engineers, designers, and stakeholders with comprehensive insights into seismic resistance analysis and modeling, enabling them to develop resilient structures that can withstand seismic forces and contribute to the safety and longevity of our built environment.

The building model must accurately reflect the distribution of stiffness and mass so that all significant forms of deformation and inertial forces are considered in the seismic analysis under consideration. In the case of a nonlinear analysis, the model, in addition to the listed factors, must adequately represent the strength distribution. The floor slab is considered a rigid diaphragm if, in seismic calculations accounting for its actual flexibility, the displacements of the floor slab do not exceed more than 10% of the values obtained assuming it is perfectly rigid. The model must also account for the influence of joint connections on the deformability of the building, such as the end zones of beams or columns in frame-type structural systems. Non-structural elements capable of affecting the response of the main seismic structures must also be considered.

In general, a structure can be represented as a combination of multiple vertical structures and systems connected by horizontal diaphragms, which bear both vertical and horizontal loads. In cases where building floors can be treated as rigid diaphragms within their planes, the masses and moments of inertia of each floor can be concentrated at the center of gravity. Wall infills of frames, significantly increasing the horizontal stiffness and strength of buildings, should be taken into account. The deformability of the foundation (including the interaction of the foundation structure with the base) can always be considered in the calculation, including cases where it has a positive effect.

In order to account for uncertainties in the distribution of masses, as well as the spatial variation of seismic motion, the calculated centers of mass on each floor, denoted as "i," should be considered as displaced from their nominal positions in each direction by a value equal to a random eccentricity:

$$e_{ai} = \pm 0.05 \cdot Li \qquad (1)$$

Where:

- e_{ai} represents the random eccentricity of the mass on floor *i* from its nominal position, assumed to be in the same direction on all floors.
- Li is the size of the floor perpendicular to the direction of seismic action.

Linear Methods of Analysis. Depending on the structural characteristics of the building, one of two types of linear elastic analysis can be used:

a) "Force-based analysis" for buildings that meet the code requirements.

b) "Response spectrum modal analysis," which can be applied to all types of frame buildings.

As an alternative to the linear method, nonlinear methods can also be applied:

c) Nonlinear static analysis (based on the sequence of structural element failure under applied load).

d) Nonlinear time history analysis (direct dynamic analysis).

The linear elastic analysis of a structure that meets regularity criteria in plan can be performed using two plane models, one for each main horizontal direction. Depending on the building's importance class, its linear elastic analysis can be carried out using two plane models, one for each main horizontal direction, even if the plan regularity criteria are not satisfied.

The seismic shear forces at the base of the building, F_b, for each horizontal direction in which the building is analyzed, must be determined using the following equation:

$$F_b = S_d(T_1) \cdot m \cdot \lambda \qquad (2)$$

Where:

- $S_d(T_1)$ is the ordinate of the design spectrum at period T_1.
- T_1 is the fundamental period of horizontal vibration of the building in the considered direction.
- m is the total mass of the building above the foundation or above the top of the rigid foundation.
- λ is the correction factor, with a value of $\lambda = 0.85$ if $T_1 \leq 2$ times the natural period of the structure and the building has more than two stores, and $\lambda = 1.0$ in other cases.

The coefficient λ takes into account the fact that in buildings with three or more stores and translational degrees of freedom in each horizontal direction, the effective modal mass of the first (fundamental) mode of building vibration is on average 15% less than its total mass.

To determine the fundamental period of vibration T_1 of the building, you can use equations based on structural dynamics methods (e.g., the Rayleigh method). For buildings up to 40 meters in height, you can approximately determine T_1 (in seconds) using the following equation:

$$T_1 = C_t \cdot H^{3/4} \qquad (3)$$

Where:

- C_t is 0.085 for spatial steel frames with moment-resisting connections, 0.075 for spatial concrete frames with moment-resisting connections, and for steel frames with eccentric connections, and 0.050 for all other structures.
- H is the height of the building in meters, measured from the foundation or the top of the rigid foundation.

The value of C_t in equation (3) can be determined as:

$$C_t = 0.075 / \sqrt{A_c} \qquad (4)$$

Where:

$$A_c = \sum [\, A_i \cdot (0.2 + (l_{wi}/H)^2)] \qquad (5)$$

- A_c is the total effective wall area on the first floor of the building in square meters.

- A_i is the effective cross-sectional area of wall i that resists shear in the considered direction on the first floor of the building in square meters.
- H is the height of the building.
- l_{wi} is the length of wall i that resists shear on the first floor in the direction parallel to applied forces in meters, with the limitation that l_{wi}/H does not exceed 0.9.

The fundamental modes of building vibration in horizontal directions can be calculated using structural dynamics methods or approximated by horizontal displacements that increase linearly with building height.

Nonlinear Methods of Analysis. The mathematical model used for elastic analysis must be developed to include descriptions of the strength of structural elements and their post-elastic behavior. At the element level, at a minimum, a bilinear force-deformation relationship should be used. For reinforced concrete, the elastic stiffness of the bilinear force-deformation relationship should correspond to the stiffness of sections with cracks. For plastic elements where deviations from elastic behavior are expected to occur beyond the yield point, the elastic stiffness of the bilinear relationship should represent the stiffness of the secant to the yield point. Trilinear force-deformation relationships are allowed, which account for the stiffness of the element before and after cracking. After reaching the yield point, a zero-stiffness assumption is permissible. If strength degradation is expected, it should be accounted for in the force-deformation diagram of these elements. Unless otherwise specified, the properties of elements should be based on average material property values. For new structures, average material property values can be estimated based on relevant characteristic values found in material standards.

Gravitational loads should be applied to the corresponding elements of the mathematical model. When determining force-deformation relationships for structural elements, axial forces from gravitational loads should be considered. Bending moments arising in vertical structural elements from gravitational loads, if they do not significantly affect the overall structural behavior, can be neglected.

Seismic effects should be applied in both positive and negative directions, using maximum seismic effects. If a nonlinear static analysis is performed (based on the sequence of structural element failure under applied load), the vertical component of seismic action can be disregarded.

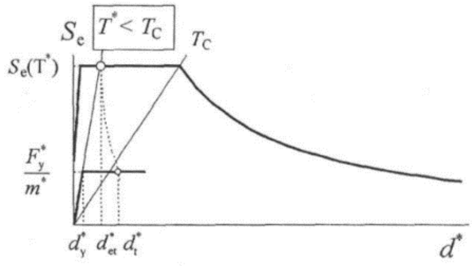
Calculation of Displacements. If a linear analysis is performed, the displacements caused by the calculated seismic action can be determined based on the elastic deformations of the structural system using the following simplified equation:

$$d_s = q_d * d_e \tag{6}$$

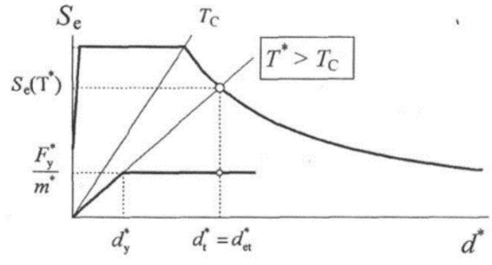
Where:

- d_s is the displacement of a point in the structural system caused by the calculated seismic action.
- q_d is the displacement behavior coefficient, taken as q unless specified otherwise.
- d_e is the displacement at the same point in the structural system determined from the linear analysis results.

The value of d_s should not exceed the value obtained from the elastic spectrum. Typically, q_d is greater than q if the period of the structure's vibration in the fundamental mode is less than T_c (refer to the Figure).



a) Short period range



b) Medium and long period range

Figure - Determination of Prescribed Displacements for an Equivalent Single-Degree-of-Freedom System. a) Short Period Range; b) Medium and Long Period Range

When determining displacements (de), it is necessary to consider the torsional effects of seismic action. For both static and dynamic analyses, the displacements determined in this manner are accepted directly from the analysis without further modification.

In conclusion. This article has explored various aspects of seismic analysis in structural engineering. It has highlighted the significance of selecting the appropriate analysis method, considering material properties, and applying accurate seismic forces. Prescribed displacements and their role in structural design have been discussed, emphasizing their importance in ensuring the safety and performance of buildings during seismic events. The choice between linear and nonlinear analysis methods depends on the specific characteristics of the structure and the desired level of accuracy. This article provides valuable insights for engineers and designers involved in seismic design and structural analysis, ultimately contributing to safer and more resilient structures in earthquake-prone regions.

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