# Finite Element Analysis of Row Structures Applied to Displacement Control of Elevated Cold Stores

**Jialiang Yang[1*], Ke Liu[2]**
[1] Hua Shang International Engineering Co., Ltd., Beijing, China
[2] Beijing YJK Building Software Co., Ltd., Beijing, China
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**Abstract:** A single-storey elevated cold store adopts a concrete single-span double-slope rigid-jointed row frame structural system, which is characterised by high eaves and large spans, and requires high seismic performance. This paper takes this single-storey elevated cold storage as an example, and applies the vibration mode decomposition reaction spectrum method (CQC) to analyse the displacement response of the structure under multiple-occurrence earthquakes and rare-occurrence earthquakes, so as to derive the displacement control effect of the structure under different working conditions. Pushover analysis (pushover) of this rack structure is carried out using static elasto-plastic analysis (PUSHOVER) to assess the performance points of the structure under seismic actions. The results show that the displacement of this rack structure is well controlled under seismic action, which meets the code requirements and maintains a high shear capacity under rare earthquakes. In addition, the static elastic-plastic analyses (pushover) show that the performance points of the structure under multiple-occurrence, fortified, and rare-occurrence earthquakes are as expected, verifying that the seismic design of the structure is reasonable.
***Keywords*:** row frame structure, elevated cold storage, finite element analysis, seismic performance, displacement control

## 1. Introduction

As elevated cold storage has the characteristics of high gable and large span, it makes it easy to produce large displacement under earthquake and wind loads, which in turn affects the stability and safety of the structure[1] . With the rapid development of cold chain logistics, the structural safety and stability of elevated cold storage, as an important part of cold chain logistics, is particularly important. Racking structure is widely used in elevated cold storage because of its unique structural characteristics and better economy. In-depth study of displacement control of rack structure in elevated cold storage is the key to ensure structural safety and improve the efficiency of cold chain logistics[2] .

## 2. Overview of the project

A single-storey elevated cold store is a typical cold chain logistics facility, the technical parameters and structural choices in its design and construction reflect the high standards and strict requirements of modern cold chain logistics buildings. The eaves height of a single-storey elevated cold store is 38m, adopting concrete single-span double-slope rigidly jointed rack structure system and light steel maintenance at the periphery, with concrete columns size H1475×1000 and steel beams size H1800×500×20×36. The project is located in a site with seismic fortification intensity of 7 degrees (0.10g), site category of Class II, site roughness category of Class A, and basic wind pressure of 0.75 kN/m2. And the wind load coefficients are 0.8 on the windward side, -0.6 on the leeward side, and -0.6 on the double-slope roof. The column boundary conditions are articulated at the top of columns and embedded at the bottom of columns. In terms of loading, the constant roof load of 6kN/m2 and the live roof load of 1kN/m2 are set to take into full consideration of the various possible situations of goods storage and personnel activities in the process of using the cold storage. In order to better analyse the seismic performance of the rack structure, one of the bays is taken for seismic analysis (Figure 1).

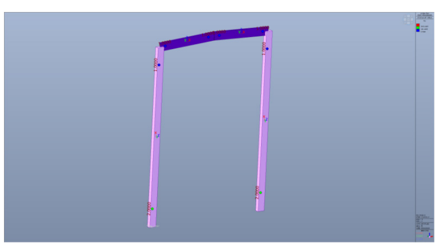
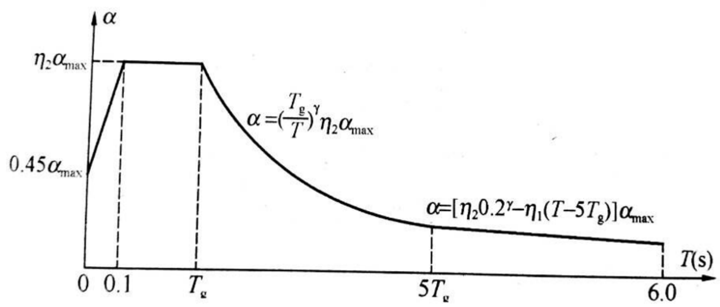


**Figure 1. Single-bay calculation model**

## 3. Seismic analysis under multiple earthquakes using the mode decomposition reaction spectrum method

The seismic effect coefficient curve of the building structure is shown in Figure 2 according to the "Code for Seismic Design of Buildings" (GB50011-2010). The seismic effect coefficient curve of building structure is shown in Figure 2. The designed seismic grouping of the area where this structural high-rise building is located is Group II, the seismic intensity is 7 degrees, and the site category is Type II. The design seismic grouping of the area where this combined structure high-rise building is located is Group II, the seismic intensity is 7 degrees, the site category is Class II, the design basic seismic acceleration peak is 0.1g, the structural damping ratio is 0.02, and the roughness category of the site is Class A. The seismic effect coefficient curve of frequent earthquake applied on the structure are shown in Figure 3.




α-Seismic affecting coefficient; $\alpha_{max}$-Maximum seismic affecting coefficient;

$\eta_1$-The downward slope adjustment coefficient for the straight downward segment;

γ-Attenuation index; Tg-Eigenperiod; η2-Damping adjustment coefficient; T-Structural period

**Figure 2. The seismic effect coefficient curve**

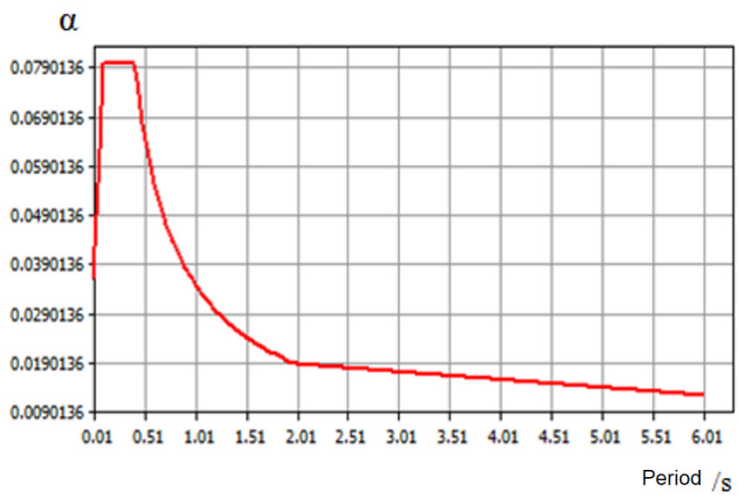



**Figure 3. The seismic effect coefficient curve of frequent earthquake**

Using the vibration mode decomposition response spectrum method, the seismic displacement response of the structure was calculated to be 0.039m for multiple earthquake events, with the maximum value of the interstorey displacement angle being 1/1000.

## 4. Seismic analysis under rare earthquakes using the pushover method

### 4.1 Overview of static elasto-plastic analysis

Static elasto-plastic analysis, also known as Pushover analysis, is now considered as one of the practical performance-based seismic design methods. The so-called performance-based seismic design is to use a certain target performance as the design control objective, not simply to meet the ultimate load carrying capacity required by the code, but through the performance evaluation analysis can check the reasonableness of the structural design and determine whether the design should be further optimised. The Pushover analysis method uses target displacement as the design control objective to evaluate the deformation capacity (energy dissipation capacity) of the structure, so it is also known as the displacement-based design method[3] .

## 4.2 Main processes of static elasto-plastic analysis methods

The approximate procedure for calculating the Pushover analysis of a structure is as follows[4]:

(1) Calculation of vertical structural loads. Vertical loads are composed of structural self-weight (self-weight of members, levelling, decoration, etc.) and floor use loads. During the whole process of pushing and overturning, the vertical load always acts on the structure and its size is unchanged.

(2) Apply horizontal load. Commonly used horizontal load distribution patterns include uniform distribution, inverted triangle distribution, and horizontal force distribution obtained by combination of vibration mode decomposition method.

(3) Determine the performance level of the structure from a macroscopic point of view. Firstly, the capacity curve of the structure should be established, then transformed into capacity spectrum through the capacity curve, and then transformed into demand spectrum by each response spectrum curve of the corresponding site, and then react the capacity spectrum curve and the demand spectrum curve together in the same coordinate system, that is to say, to establish the ADRS spectrum, and if the capacity spectrum intersects with a certain demand spectrum, it means that the structure is able to resist the seismic intensity of the response spectrum curve corresponding to that demand spectrum.

(4) Determine the nonlinear performance of structural members and the interstorey deformation performance of the structure.

## 4.3 Capacity and Demand Spectrum

The capacity spectrum method is to load gradually to the control target in the specified loading mode and obtain the lateral shear-vertex displacement curve of the structure, and then transform the lateral shear-vertex displacement curve into the capacity spectrum curve by using equations (1) and (2):

$$S_a = \frac{V_b}{M_1^*}, S_d = \frac{U_T}{\Phi_{N1}} \tag{1}$$

$$M_1 = \frac{\left(\sum_{j=1}^{N} m_j \Phi_{ji}\right)^2}{\sum_{j=1}^{N} m_j \Phi_{ji}}, \tau_1 = \frac{\sum_{j=1}^{N} m_j \Phi_{ji}}{\sum_{j=1}^{N} m_j \Phi_{ji}^2} \tag{2}$$

$S_a$ — spectral acceleration; $S_d$ —spectral displacement; $V_b$ — shear force; $U_T$ — displacement;

$M_1^*$ — the effective mass with respect to the fundamental vibration mode; $\tau_1$ — the vibration participation factor of the fundamental vibration mode;

$\Phi_{N1}$ — displacement of the top of the structure at the fundamental vibration mode; $m_j$ — concentrated mass at the nodes;

$\Phi_{ji}$ — The displacement of node j in $\Phi_i$ at i vibration mode.

At the same time, the seismic response spectrum influence coefficient curve is transformed into a spectral acceleration-spectral displacement demand spectrum curve by equation (3):

$$S_d = \frac{S_a}{\omega^2} = \frac{T^2}{4\pi^2} S_a \tag{3}$$

$T_g$ — eigenvalue period; T — structural self-oscillation period

Then the capacity spectrum curve and the demand spectrum curve react together in the same coordinate system, i.e. to establish the ADRS spectrum, the intersection of the two curves of the capacity spectrum and the demand spectrum is the performance point, which represents the ultimate load carrying capacity and the deformation capacity point of the level of seismic action[5] .

## 4.4 Results of static elasto-plastic analyses

The target displacement of the structure was 4m and was divided into 20 steps of 0.2m each, with the control point being the apex of the single-bay rack. At the control point, the structure was loaded step by step along the in-plane direction of the single-bay raft to simulate its response under increasing horizontal displacement.

The performance point of the structure under frequent earthquake is at the coordinates (0.03283, 0.01715), and the maximum inter-story displacement angle at the performance point is 1/1188 (Figure 4). The displacement response of the structure is relatively small in the case of frequent multiple earthquakes, but its stability and safety still need to be concerned. The structure at this stage is mainly in the elastic phase, with a linear relationship between displacement and load. At this time, the structural design should meet the elastic design requirements to ensure that the safety and functionality of the structure will not be affected under small earthquakes.

The coordinates of the performance point of the structure under defended earthquake are (0.1127,0.04794), and the maximum interstory displacement angle at the performance point is 1/346 (Figure 5), reflecting the response of the structure under moderate intensity seismic action. At this stage, the structure can enter the elastic-plastic stage, and the relationship between displacement and load begins to show nonlinear characteristics. At this time, the structural design should take into account the plastic deformation capacity to ensure that the structure does not undergo serious damage under a moderate intensity earthquake and can continue to be used after repair.

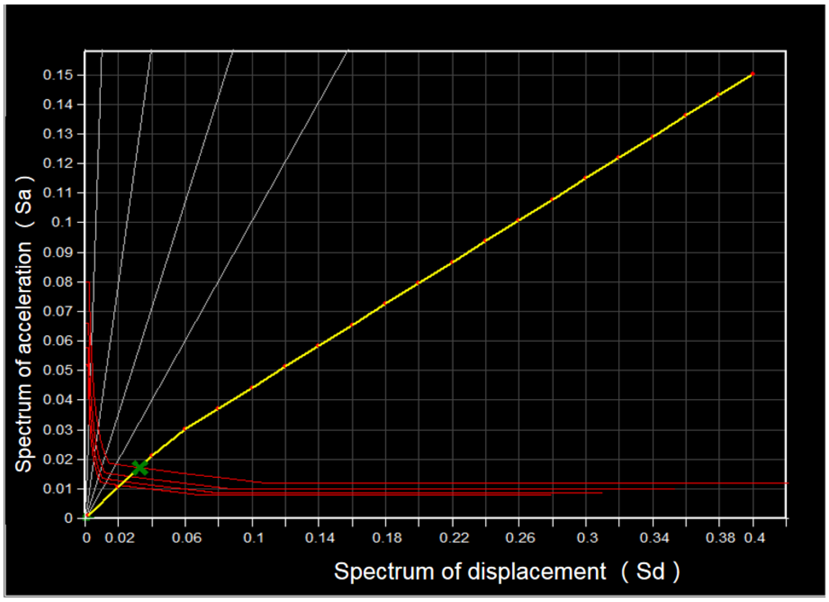



**Figure 4. ADRS curves of the structure under frequent earthquake**

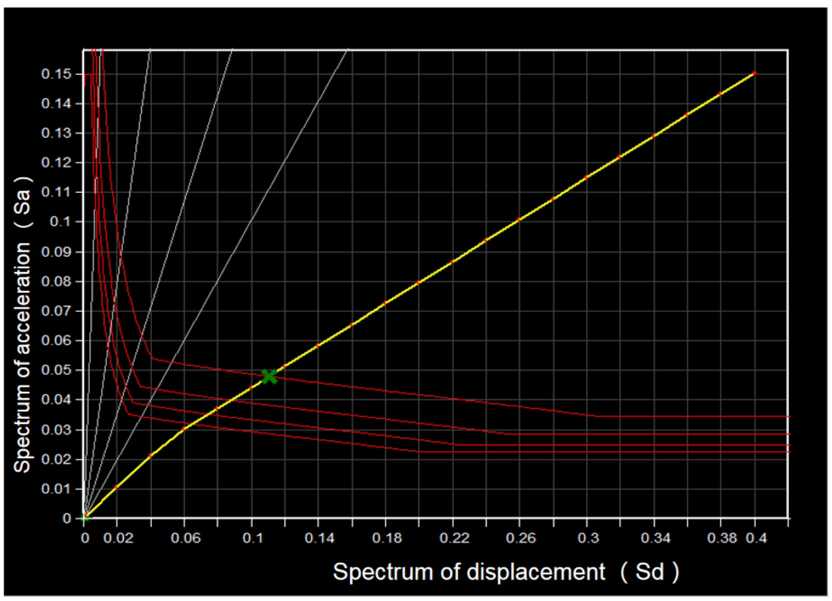



**Figure 5. ADRS curves of the structure under defended earthquake**

The coordinates of the performance point of the structure under rare earthquake are (0.2023m, 0.08026) revealing the ultimate performance of the structure under the action of rare earthquakes, and the maximum interstorey displacement angle at the performance point is 1/193. At this stage, the structure experiences large plastic deformation, and even local damage occurs. However, reasonable seismic design and structural measures can protect the structure from overall collapse under the action of rare earthquakes, thus protecting people's lives and properties.

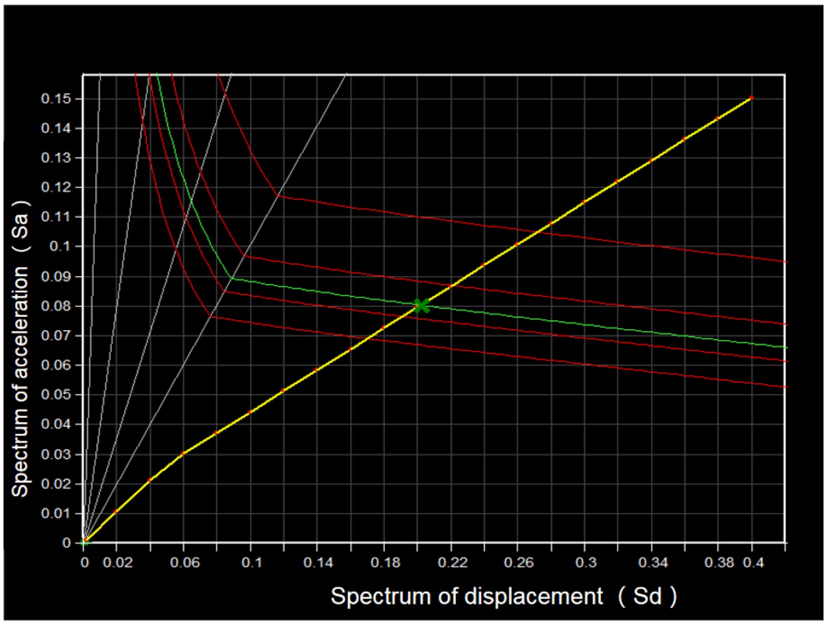



**Figure 6. ADRS curves of the structure under rare earthquake**

## 5. Concluding remarks

In this study, the performance of the elevated cold storage rack structure under seismic action is investigated in depth, and the displacement response, seismic performance and stability of the structure are comprehensively evaluated under multiple-occurrence earthquakes, fortified earthquakes, and rare earthquakes by using CQC analysis and Pushover analysis. The results show that the elevated cold storage of the rack structure exhibits good stability and safety under the design load, but the risk of local damage and overall instability under rare earthquakes still needs to be concerned. Based on this, a series of measures are proposed to improve the overall stiffness and strength of the structure, reasonably arrange the supporting and connecting members, and set up seismic energy dissipation devices, so as to enhance the seismic performance of the structure.

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